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ACL Reconstruction & Lessons Learned
Accelerated Vs. Decelerated Rehab Management of Anterior Cruciate Ligament
Recovery Science & Load Monitoring
Psychological Readiness & Return to Sport
Preventing Subsequent ACL Injury

Meniscal Pathology
Predictors for Nonoperative Success
Early vs. Delayed Weight-Bearing

The Aging Athlete
Optimizing Rehab Following Shoulder Arthroplasty
Surgical Treatment Options for the Aging Knee
Return to Sport After Total Hip & Total Knee Replacement: What I Tell My Patients
The Acute Achilles Rupture: Nonop Vs. Surgical Tx

Hip
Extra-Articular Hip Pathology: When It Is Not The Joint
Core Muscle Injury or Hip Injury: The Differential Diagnosis
Assessment & Diagnosis of Posterior Hip Pain
Greater Trochanteric Pain Syndrome
Conservative Vs. Surgical Management
Return To Elite Cutting & Pivoting Activities

Intra-Articular Controversies
FAI: Myth or Reality
Pincer Vs. Cam Vs. Mixed Impingement Tx
MRI Findings to Make the Correct Diagnosis

Shoulder
Shoulder Instability: Anterior, Posterior, & MDI
First Time Shoulder Dislocation: Op Vs. Nonop Tx
Bone Loss & Shoulder Instability: Surgical Options
Matching Rehab to Surgery: An Algorithm for Success
Isokinetic Evaluation & Progression
Successful Rehabilitation of Rotator Cuff Injuries
The Shoulder Exam Made Simple
Massive Rotator Cuff Tears & Restoring Elevation
Fast or Slow: Postop Rotator Cuff Rehabilitation
Unfreezing the Frozen Shoulder

Technology & Sports
Blood Flow Restriction & Strength Recovery
Optimization of Rehab & Home Exercise Compliance
Movement Quality & Return to Play Guidelines
Rehabilitation Following Orthobiologics
Pro Athletes: The NHL, PGA, ATP, & MLB Experience

Spine
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The Cervical Spine: Diagnostic Exam Pearls
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Clinical Pearls for Spine Recovery Rehab & Postop Opioid Use

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EDITORIAL

THE USE OF BIG DATA TO IMPROVE HUMAN HEALTH: HOW EXPERIENCE FROM OTHER INDUSTRIES WILL SHAPE THE FUTURE

By Timothy E. Hewett, PhD and Kate Webster, PhD

The article in the current issue of the International Journal of Sports Physical Therapy entitled “Using Big Data to Improve Human Health: How Experience from Other Industries Will Shape the Future” is both highly relevant and important to the readership of IJSPT as it will challenge our thinking of traditional clinical and research paradigms and approaches and present new possibilities.

The goal of traditional medical and biostatistical inquiry has been to determine cause and effect, and hence predictive relationships between independent and dependent variables that are hypothesized to be important to human health. Early twentieth-century biostatisticians (see the great Ronald Fisher, for example) therefore established randomized control trials (RCTs) and data science approaches that aimed to compare the differences between test groups (intervention versus “control”). These traditional medical biostatistical approaches compare the differences between test groups (intervention versus “control”) as the numerator and the measurement error in the denominator of the equations. Hence, the focus of these comparisons relies on highly precise measurements of both the differences between groups and the errors between groups, which are often quite challenging to determine. More recent data science approaches that utilize Artificial Intelligence schemes, such as Machine Learning and Neural Networks, do not require as much precision as they model off big data sets and rely on Big Data inputs to develop predictive algorithms.

It was purported by these early biostatisticians that cause and effect could only be determined with medical biostatistical approaches that utilized RCTs. However, subsequently clinicians together with biostatisticians have attempted to determine cause and effect relationships using clinical cohort studies. Association and prediction are the key concepts that are sought for and utilized in these analyses. Obviously, these cohort studies can help us to determine the association, but can these studies actually be utilized to determine causation and to develop predictive algorithms? For example, clinical cohorts are regularly used to draw cause and effect relationships between musculoskeletal parameters such as body mass, and musculoskeletal injury, such as knee, ankle or shoulder, risk. This is especially the case for clinical questions in which RCTs would be unethical or impossible to conduct. Validation of these findings from clinical cohorts then become of crucial importance.

Studies of the reliability and validity of these cohort findings become necessary. These studies can be highly challenging, especially with limited datasets. There remains a substantial gap between these approaches and the determination of cause and effect and predictive relationships between these limited numbers of independent and dependent variables. Many important questions are raised in the article in this issue of IJSPT, which include:

- How does the biomedical statistical approach compare to these newer “Big Data” analyses?
- How can Artificial Intelligence approaches help us to accomplish these predictive goals with greater reliability and validity?
- Can we combine traditional and Machine Learning approaches for the determination of both cause-and-effect relationships and enhanced predictive capacity that can lead to markedly improved clinical outcomes?

As the authors of this paper point out, the convergence of the two disparate approaches will be key to future advancements in biomedical research and its clinical utility.
Sports physiotherapy – Actions to optimize the health of Para athletes

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SPORTS PHYSIOTHERAPY – ACTIONS TO OPTIMIZE THE HEALTH OF PARA ATHLETES

The interest and development of Para sport continues to increase around the globe. As Para athletes’ performances and professionalism are steadily improving, there is also an increasing need and interest for athlete health and (para)-medical support. The term Para athlete refers to individuals with an impairment that participate in a sport that has classification rules as defined in the International Paralympic Committee (IPC) Athlete Classification Code (www.paralympic.org).

This calls for further scientific knowledge and professional competencies. We believe that physiotherapists are crucial partners in this regard. In this IFSPT perspective, we have summarized how sports physiotherapists can add value within various settings of Para sport.

ASSESSMENT AND ATHLETE HEALTH MONITORING

To increase the knowledge of Para athletes’ health, it has been recommended to conduct athlete health monitoring on a regular basis.1 With experience in classifying health, functioning and disease, physiotherapists again can provide valuable knowledge into this area. The same applies to the assessment of injury. As indicated above, special attention is required for Para athletes given their uniqueness, both as individual athlete, and by nature of their injuries. Most recently, this was expanded upon in the area of concussion assessment, with a call for case-by-case decision-making.2

Athlete classification is a very specific application of assessment in which athletes are "classified" according to their ability to perform certain movements and tasks.3 Therefore, every athlete undergoes an extensive physical and sport-specific assessment. By nature of their qualification and skills, sports physiotherapists act as classifiers alongside physicians and sports experts across almost all Para sports. For more detail, the reader is referred to www.paralympic.org and Journal of Sports Sciences.4

REHABILITATION OF SPORTS INJURIES IN PARA SPORT

Para athletes report higher rates of sports injuries and illnesses compared to able-bodied athletes.5,6 For an athlete with an impairment, a sports injury or illness may not only affect sporting participation and performance, but also exacerbate the existing, underlying disability and compromise the athlete’s ability to perform activities of daily life.4,7

Alongside injuries that often are similar to those of their able-bodied counterparts, Para athletes also report specific impairment- and equipment-related sport injuries.5,8 For example, poor proprioception can contribute to injuries in athletes with vision loss, whereas low bone mineral density and spasticity may increase the risk in athletes with neurological impairment. Therefore, it is important that the Para athlete is provided with strategies that can be applied both in sports and in daily life.

Thanks to a broad knowledge of musculoskeletal and neurological systems, sports injuries, the restoration of function and movement following an injury, and disability in general (impairments, activity limitations and participation restrictions), physiotherapists have an important role to play in supporting Para athlete health and welfare.

PREVENTION OF SPORTS INJURIES IN PARA SPORT

Physiotherapists are masters of the adage: “one size does not fit all.” For example, an athlete with transfemoral amputation or high spinal cord injury will not benefit from a regular knee control programme. Evidence-based physiotherapy focuses on tailored, patient-centred prevention.
programmes with an emphasis on behavioural science, health promotion and education, just what Para athletes need! In this sense, our profession has an important task to fulfill in the continuous development of holistic prevention strategies.

A very specific application of this knowledge is guiding athletes in their adaptive sports-specific equipment choice and its fitting (e.g. racing chair, sit-ski, running prosthesis). Thanks to the extensive knowledge of anatomy, ergonomics and assistive devices, physiotherapists will be able to assess the importance and impact of specific equipment and assistive devices as an additional component of medical care and prevention. 4,10

GETTING INVOLVED

We advocate for sports physiotherapist engagement in Para sports:

• Sports physiotherapists are needed in the athlete support team. As a licensed health care practitioner with knowledge of disability and functioning, the musculoskeletal, nervous and cardiovascular system, and experience of working within multidisciplinary teams and biopsychological contexts, physiotherapists can advantageously take responsibility for the medical team during events and competitions.
• As academic professionals, sports physiotherapists play an important role to expand systematic data collection on injury and illness epidemiology in this population. Such data are needed to develop evidence-based treatment strategies, medical support, prevention programmes, and assessment methods.
• With classification moving into more evidence-based decision making, sports physiotherapists need to be involved in this process, as they are experts on human movement assessment.
• Sports physiotherapists must engage in increasing Para sport opportunities and share knowledge with fellow colleagues within the medical field.

Taken together, Sports Physiotherapists play an important role in understanding, promoting, assessing, maintaining, and restoring health in Para athletes around the globe. Ask yourself: are you doing your part?

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Clinical Viewpoint

Evidence Based Arm Care: The Throwers 10 Revisited

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THE EVOLUTION OF BASEBALL ARM CARE

Over the past 40 years sports medicine physicians, physical therapists and performance experts have continually worked to advance treatment paradigms for the throwing athlete. The progression of evidence-based arm care has taken generations of innovators to get to where we are today. In 1983, Dr. Frank Jobe pioneered the original EMG study on the deltoids, subscapularis and what they referred to as the “SIT” muscles (supraspinatus, infraspinatus, and teres minor) during the pitching motion.1 This work continued to advance through the 1980s and early 1990s with Jobe et al.1 and DiGiovine et al.2 giving clinicians a better understanding of the muscle activity and performance demands of the entire upper extremity during the pitching motion. This work set the stage for researchers like Mosely et al.3, Blackburn et al.4 and Townsend et al.5 to investigate which exercises would be most beneficial for the throwing athlete, allowing innovators like Kevin Wilk and James Andrews to develop the Thrower’s Ten Exercise Program in 1991.6

In 2011, Wilk et al.7 introduced the "Advanced Thrower’s Ten". This expanded program incorporated throwing motion-specific exercises and movement patterns performed in a discrete series, utilizing principles of coactivation, high-level neuromuscular control, dynamic stabilization, muscular facilitation, strength, endurance, and coordination, which all serve to restore muscle balance and symmetry in the overhead throwing athlete.7 The evolution of these arm care programs has been an asset to the baseball community, offering the opportunity for pre-season and off-season strengthening for injury prevention and sports performance.

The Yokahama Baseball-9 (YKB-9) and the modified Yokahama Baseball-9 (mYKB-9) are prime examples of an arm care program that has been researched and modified to show its efficacy.5,9 Although the exercises do not appear to all be evidence-based, the testing and modification of the program has shown desired effects. The goal of any arm care program is not only to show strength improvements, but also show the desired effects on injuries. Evolving the arm care programs needs to include a research-based program that can offer in-season strengthening and maintenance that can easily be performed in any setting, on the road, with minimal equipment.

BUILDING ON THE GOLD STANDARD

At the Nicholas Institute of Sports Medicine and Athletic Trauma (NISMAT), our founder James A. Nicholas, MD was paramount in offering evidence-based medicine that addressed not only the injury, but the athlete. In 1976, Dr. Nicholas developed the concept of linkage by highlighting the importance of proximal stability for distal mobility.10 This concept has been the catalyst for developing the NISMAT Arm Care program. To maintain a healthy throwing arm, we needed to provide evidence-based exercises that not only address strength but also address flexibility and endurance from the trunk to the hand.

The goals of developing the NISMAT Arm Care program were: (1) Exercises should be evidence-based. Focused exercises that are evidence-based will maximize the efficiency of the arm care program. (2) Develop a program that considers the concept of linkage described by James A. Nicholas. (3) Develop a program that is portable and can be performed in any setting. In today’s baseball lifestyle, players, trainers, and parents are always on the road with minimal access to high level, expensive strength equipment. This program was designed to utilize elastic-resistance exercises with no additional equipment required.

Developing this NISMAT Arm Care Program was a three-step process. Step 1: The Arm Care team first reviewed the early pioneering EMG studies identifying which muscles were activated during the pitching motion.1,2 This enabled our team to develop a list of muscles that needed to be addressed in an arm care program. Step 2: The team then identified which exercises have sufficient evidence to support their use for training specific muscle groups. A review of the EMG literature was performed to find the top exercises that would address these specific muscles activated during pitching. During this step we determined there was
little evidence supporting exercises for the flexor pronator mass. Additionally, no EMG studies have examined which muscles are activated during the commonly used pull-apart exercises. Step 3: The final step was to fill the gap in the literature by providing evidence for exercises that are presumed to target muscles involved in the throwing motion. In this current issue of the *International Journal of Sport Physical Therapy*, two of these studies have been included to add evidence to these prescribed exercises.

**NISMAT ARM CARE PROGRAM**

The NISMAT Arm Care program addresses musculoskeletal strength and mobility during each of the stages of pitching. Below you will find each exercise included in the NISMAT ARM Care program, the target muscle or movement, and the phase of pitching in which the specific muscle is working at its peak. This breakdown can also be found in Table 1. Appendix A has photos and a link to the formal program.

**PUSH–UP PLUS (OPTIONAL BAND)**  
**https://videos.files.wordpress.com/3dprvtml/pushup-plus_hd.mp4**

This exercise was chosen to address serratus anterior. The scapular muscles play a large role in the stability and foundation of the throwing arm. From the late cocking to the deceleration phase the serratus anterior maintains an EMG level between 51 and 106% Maximum Volitional Contraction (MVC) with the peak MVC occurring during late cocking. To help address the serratus anterior we chose the push-up plus. Multiple studies rank this exercise as the most effective serratus anterior exercises reaching between 90 to 104% MVC. The NISMAT Arm Care program also recommends incorporating the use of elastic resistance to increase the MVC while performing the exercise.

**BILATERAL EXTERNAL ROTATION WITH SCAPULAR RETRACTION**  
**https://videos.files.wordpress.com/zykly4k8/bl-er-scap-retraction_hd.mp4**

This exercise was chosen to address lower trapezius muscle strengthening. During the pitching motion, the lower trapezius muscle activity reaches between 76–78% MVC during the acceleration and deceleration stages. McCabe et al. highlighted this exercise as one of the best exercises for activating lower trapezius activity while minimizing upper trapezius activity.

**STANDING HORIZONTAL ABDUCTION WITH NEUTRAL HAND POSITION**  
**https://videos.files.wordpress.com/s2nbivy1/horz-abd-neutral_hd.mp4**

This exercise was chosen to address posterior deltoid strengthening. During the acceleration and deceleration stages of pitching, the posterior deltoid muscle activity reaches between 60–68% MVC. Townsend et al. found this exercise to isolate the posterior deltoid and infraspinatus. The posterior deltoid reaches levels of 95% MVC during this exercise.
LAWNMOWER [HTTPS://VIDEOS.FILES.WORDPRESS.COM/MA5YTBB87/LAWNMP5ER_HD.MP4]

This exercise was chosen to address both lower trapezius and posterior deltoid strengthening. As stated previously, lower trapezius muscle activity can reach as high as 78% MVC, while the posterior deltoid can reach up to 68% MVC during acceleration and deceleration. This lawnmower exercise has been shown to reach activation levels of the lower trapezius as high as 30% and posterior deltoid up to 52% MVC.15,16

STANDING DIAGONAL BAND PULL-APART
[HTTPS://VIDEOS.FILES.WORDPRESS.COM/IRERWSKE/STANDING-DIAGONAL-PULL-APART_HD.MP4]

This exercise was chosen to address supraspinatus, middle trapezius, and posterior deltoid. The supraspinatus activity can reach 60% MVC and middle trapezius 68% MVC from cocking to acceleration while posterior deltoid activity can reach 68% MVC from acceleration to deceleration. Fukunaga et al.15 highlighted this exercise with a neutral grip can elevate MVC activity in supraspinatus (60%), middle trapezius (58%), upper trapezius (64%) and posterior deltoid (54%).

STANDING ROW WITH 90/90 EXTERNAL ROTATION
[HTTPS://VIDEOS.FILES.WORDPRESS.COM/TAXBOY2F/STANDING-ROW-9090ER-EDIT.MP4]

This exercise was chosen for activation of the infraspinatus and teres minor. During the motion of the infraspinatus peaks muscle activity during the late cocking phase (74%), while the teres minor muscle activity peaks during the deceleration stage (84%).2 This exercise has been shown to activate the infraspinatus between 50-88% MVC, while teres minor activation will reach a lower level of 39% MVC.5,12,18,19 The NISMA Arm Care program encourages this exercise to start with a scapular retraction during the row. Schacter et al.20 showed that external rotation strength is higher when initiated with scapular stabilization.

SIDE PLANK WITH EXTERNAL ROTATION
[HTTPS://VIDEOS.FILES.WORDPRESS.COM/OOPDXANYZ/SIDEPANK-SHOULDER-ER_HD.MP4]

This exercise was chosen for activation of infraspinatus, supraspinatus, teres minor and posterior deltoid. This exercise has been shown to activate these muscles: infraspinatus 42-62% MVC, supraspinatus 51% MVC, teres minor 67% MVC and posterior deltoid 52% MVC.12,18 The NISMA Arm Care program, based on Krause et al.21 recommends using a side plank position to elevate the muscle activity in posterior deltoid and infraspinatus.

SHOULDER INTERNAL ROTATION AT 90/90 POSITION
[HTTPS://VIDEOS.FILES.WORDPRESS.COM/ITYT5XAVC/SHPULD-IR-9090_HD.MP4]

This exercise was chosen for activation of the subscapularis. Subscapularis activation reaches its peak MVC during the acceleration stage of pitching (115%).2 This exercise has been shown to reach between 65-71% MVC.12,22 The NISMA Arm Care program recommends performing scapular stabilization prior to performing this exercise. Schacter et al.20 showed improved internal rotation muscle activation when performing scapular stabilization.

STANDING SCAPTION
[HTTPS://VIDEOS.FILES.WORDPRESS.COM/ON2Y0W04/STANDING-SCAPITION_HD.MP4]

This exercise was chosen for activation of the supraspinatus, middle deltoid, and teres minor. The supraspinatus reaches 60% MVC from cocking to acceleration, middle deltoid reaches 59% MVC and teres minor reaches 84% MVC during deceleration.2 A review of the literature supports the scaption exercise as a general shoulder strengthening exercise.12,18,22 The highest activation occurs in the supraspinatus 32-64% MVC, middle deltoid 38-52% MVC, and teres minor 39-110% MVC.12,18,22,23

WALL WALKS
[HTTPS://VIDEOS.FILES.WORDPRESS.COM/MCWYN5H0/TRAND-WALL-WALK_HD.MP4]

This exercise was chosen for activation of infraspinatus. During the pitching motion the infraspinatus reaches its peak MVC during late cocking (74%).2 This exercise increased EMG activity over 21% MVC between 60-90° of shoulder flexion, allowing for a safe option for infraspinatus strengthening without placing the shoulder in an impingement position.24

SEATED FOREARM PRONATION WITH THERABAND
[HTTPS://VIDEOS.FILES.WORDPRESS.COM/VMR7K5SFR/SEATED-FOREARM-PRO_HD.MP4]

This exercise was chosen for activation of the pronator teres. The pronator teres reaches 88% MVC and flexor digitorum superficialis reaches 80% MVC during the acceleration stage of pitching.2 Fukunaga et al.25 showed the pronation using elastic resistance activated pronator teres 73% MVC and the flexor digitorum superficialis 64% MVC.

WRIST ULNAR DEVIATION WITH ELASTIC RESISTANCE
[HTTPS://VIDEOS.FILES.WORDPRESS.COM/LOSXY09R7/WRIST-ULNAR-DEV_HD.MP4]

This exercise was chosen for activation of flexor carpi ulnaris. Flexor carpi ulnaris reaches 112% MVC during the acceleration stage of pitching.2 The flexor carpi ulnaris is also considered a secondary stabilizer of the ulnar collateral ligament. Fukunaga et al.25 showed the ulnar deviation with elastic resistance reached 40% MVC.
STANDING CROSSBODY ADDUCTION POSTERIOR SHOULDER STRETCH (SHOULDER AGAINST WALL)
HTTPS://VIDEOS.FILES.WORDPRESS.COM/8R58TIFG/STAND-POST-SHOUL-STRETCH_HD.MP4

This exercise was chosen to improve and maintain posterior shoulder tightness. Escamilla et al.\textsuperscript{26} highlighted the advantages of this internal rotation for maintaining internal rotation range of motion loss between innings.\textsuperscript{26} The NISMAT arm care program recommends performing this against a wall or side of dugout to maintain a more stable scapula.

QUADRUPED THORACIC ROTATION
HTTPS://VIDEOS.FILES.WORDPRESS.COM/W2UU6V2X/QUAD-THORACIC-ROT1_HD.MP4

This exercise was chosen to improve thoracic mobility. Hip shoulder separation is related to trunk velocity and ultimately pitch velocity.\textsuperscript{27} Therefore, training interventions to improve pelvic-trunk axial dissociation may increase maximal trunk rotation velocity.\textsuperscript{27}

DISCUSSION

The evolution of arm care for the baseball athlete has continued to gain evidence over the past 40 years. What was originally developed from clinical experience has gradually evolved over the years to be a more evidence-based approach to arm care for the pitcher. We have gained a better understanding of the muscular performance demands through the EMG studies of the pitching motion.\textsuperscript{1,2} As clinicians we are continually looking to prepare our athletes for peak performance and injury prevention.

Arm care programs are designed to offer both a performance component and injury prevention. Sakata et al.\textsuperscript{8} highlighted the success of the YKB-9 program at not only improving muscular variables, but the YKB-9 program showed a 49% decrease in medial elbow pain in youth pitchers 8-11 years old. The YKB-9 consisted of 9 strengthening exercises with no more resistance than the player’s glove as well as 9 stretching exercises.\textsuperscript{8} Both groups of exercises addressed upper extremity, trunk and hips.\textsuperscript{8} Understanding the limitations of an 18-exercise program, the mYKB-9 was slimmed down to 9 exercises, and after a 1-year follow-up, a reduction in both shoulder and elbow pain was noted in the players that used the program.\textsuperscript{9}

Although not all arm care programs have gone through the rigors of studying their effectiveness in the field, these studies by Sakata et al.\textsuperscript{8,9} highlight the potential impact of using arm care interventions. By simplifying the YKB-9 program Sakata et al.\textsuperscript{9} was able to increase the arm care program compliance rate from 54% to 74% showing greater gains in those who were compliant. Arm care programs need to be well thought out with consideration for strength and mobility, but also the level of complexity associated with the program. Programs that are too long, need extra equipment or various weights, offer a potential roadblock to compliance. Our team certainly realizes there are many exercises to choose from when developing an arm care program. The NISMAT Arm Care program was developed to offer the best evidence-based arm care with nothing more than elastic resistance.

The evolution of arm care programs has been an exciting journey. Early pioneers broke down the EMG activity of each muscle during each pitching phase, which led to the development of the original gold standard of arm care programs: the Thrower’s Ten. It has been exciting to see the evolution of many of these programs by their own creators. Based on experience and science, Kevin Wilk and James Andrews improved their original Thrower’s Ten and created a program more fit for the throwing athlete in the Advanced Thrower’s Ten.\textsuperscript{7} Jun Sakata created a successful arm care program in the mYKB-9 program; however, he saw the length of the program as a potential flaw.\textsuperscript{8,9} The evolution of that program led to a shorter program with improved potential for compliance. Arm care is an evolving process that needs to be re-evaluated based on the continually changing literature. The NISMAT Arm Care program is based on current EMG research using no more than elastic resistance and addressing each of the key components of the pitching motion. Our team has accomplished our 3 goals for developing the NISMAT Arm Care program. We developed a portable, research-based program, capturing the linkage component of the pitching motion. We look forward to the future of the NISMAT Arm Care program as it evolves with science.

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APPENDIX A

NISMAT ARM CARE PROGRAM EXERCISES


PUSH-UP PLUS (OPTIONAL BAND)

Wrap a resistance band around your torso at the level of mid-back and assume plank position on hands and toes, with straight elbows and feet together. Bend your elbows to lower your chest, then push up by straightening your elbows. Once your elbows are straight, push further down to bring your shoulder blades forward.

BILATERAL ER WITH SCAPULAR RETRACTION

While sitting or standing, tie a loop with a resistance band and wrap around both wrists. With elbows bent to right angles, pull the looped band apart by moving your hands out. Move your shoulder blades back as you move your hands apart.

STANDING HORIZONTAL ABDUCTION WITH NEUTRAL

While standing, hold two ends of a resistance band with your palms facing inward. Keeping your elbows straight, move your arms out to pull the band apart while moving your shoulder blades back, then slowly move your arms in towards the middle.

STANDING DIAGONAL BAND PULL-APART

While standing, hold two ends of a resistance band. Keeping your elbows straight, move one arm diagonally up and out while you move the other arm diagonally down and out. After the number of repetitions in this pattern, switch directions for your arms and repeat.

STANDING ROW + 90/90 ER

Anchor the middle of a resistance band on a secure object at about waist height. Stand back so the band is taut as you hold both ends of the band. Perform a row by pulling the band and bringing your elbows back to the level of your chest. With your elbows bent at right angles, twist your arms back so your hands come up on top. Come back to the start position by doing all of the above backwards.

LAWNMOWER

Anchor band at ankle level and stand slightly wider than shoulder width, rotated 90 degrees away from the band. "Mini-Squat" and grab the band with your hand furthest from the anchored band. Allow the band to rotate hips/spine towards the anchored band. Your feet should not move, but your chest should face the band. Pull back on band using your shoulder muscle, and rotate "trunk" back towards starting position, with band finishing at shoulder height.

SIDE PLANK + SHOULDER ER

Set up in side-lying with the arm underneath the body. Have a band wrapped around each hand. Lift into a side plank position, so the elbow and ankle are the only points of contact on ground. Emphasis on a straight line from ear, shoulder, hip, knee, and ankle from the front and top down view. Once in this position, "pin" top arm against the side of the body with shoulder blade pinched down and back. Rotate top hand towards the ceiling, while keeping top elbow pinched against body, and band anchored with lower hand. Rotate as high as possible without compensation, and slowly return to the starting position.

QUADRUPED THORACIC ROTATION

In kneeling with hands on the ground, rock back onto heels, as this will limit the motion in the low back. Put your palm on the base of your head and rotate to try to point your armpit towards the ceiling. Exhale on rotation.

Starting from the quadruped position, reach with your hand through the "window" created by the opposite arm and leg as far as possible.

These can be combined to increase and maintain spinal mobility: start your hand on the back of your head and rotate upward (as in the first video). On returning to neutral, remove your hand from your head and "thread the needle" by reaching as in the second video. Return to neutral quadruped position and repeat.

SHOULDER IR AT 90/90 POSITION

Anchor band behind the person so it is level with the top of the head. Hold band in hand of exercising arm, face away from band, and bend elbow to 90 degrees. Lift the arm so that it is parallel to the ground (90 degrees of elevation) and the elbow should be sticking straight out of the shoulder (not forward or behind). Stagger stance, with opposite foot in front as if throwing a ball. Engage core (pull ribs down), and slowly rotate the hand forward until it is parallel to the ground. Slowly return to the starting position and repeat.

STANDING SCAPTION

Hold the band in both hands and anchor under both feet. Start with both hands-on thighs, engage core and raise arms up in the scapular plane (approximately 45° from frontal plane). Continue to raise arms in this position, with thumbs pointed towards the ceiling, until you reach approximately 100°. Slowly return to the starting position and repeat.

STANDING CROSSBODY ADDUCTION POSTERIOR SHOULDER STRETCH (SHOULDER AGAINST WALL)

Leaning thoracic against wall, bring right arm to 90° of flexion in the sagittal plane with shoulder internal rotated. Place left arm over right arm and grasp your right elbow. Gradually put pressure through your left elbow to further pull your right arm into internal rotation. You will feel a pull in the outside/back of your shoulder. Now pull your right arm across your chest so your right hand goes under your left armpit. This will increase the stretch in the back of your
shoulder. Hold 30 seconds and repeat.

WALL WALK WITH THERABAND

Position your band in a loop, without slack, bring the band out to shoulder width. With your hands placed at shoulder height and shoulder width alternate walking up the wall with the pinky side of the hand. Once your elbows get to the same level of your eyes (elbows should be slightly flexed), reverse the walk back down to the starting position.

SEATED FOREARM PRONATION WITH THERABAND/CLX

In a seated position place your forearm resting on your thigh so your hand/wrist is past your knee. With your palm up, position the elastic resistance from the outside of your foot and grasp it between your thumb and first finger continuing the band through your palm so it comes to a rest past your pinky finger. Grasping the band with palm up you will now pronate or try to turn palm down. You will feel the resistance from the band as you attempt to rotate your palm down.

WRIST ULNAR DEVIATION WITH THERABAND/CLX

With your shoulders flexed to 90 degrees and elbows extended, wrap the resistance band around both hands so palms are facing down, and the resistance band is already on mild stretch. With palms facing down try to bring both thumbs away from each other towards ulnar deviation.
Clinical Viewpoint

The Youth Throwers Ten Exercise Program: A variation of an exercise series for enhanced dynamic shoulder control in the youth overhead throwing athlete

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Keywords: Overhead athlete, baseball, Glenohumeral Joint, Elbow Joint

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The overhead throwing motion is an extremely stressful athletic movement. The high velocity and repetitive nature of this activity places immense pressure on the entire body, which can frequently result in injury to the throwing arm. Extensive literature exists with regards to the management of these injuries in the collegiate and professional level athlete; and it is well understood that a multiphasic approach is required to return an individual to prior level of play. However, there is a gap in the literature which fails to address the management of youth individuals. This article presents a new and innovative approach to the rehabilitation, training and management of the youth overhead throwing athlete, The Youth Throwers Ten Exercise Program. This program addresses principles of: coactivation, coordination, dynamic stabilization, neuromuscular control, proprioception, muscle strength, endurance and scapular rhythm all of which are vital for successful performance. This exercise series utilizes bodyweight and Theraband exercises that cater to the unique characteristics of the youth athlete making it a safe way to prepare for the demands of overhead throwing activities.

Youth baseball is extremely popular, with an estimated 3 million children playing yearly in the United States alone. While baseball is a relatively safe sport, injuries are unavoidable with overuse throwing injuries to the elbow and shoulder remaining a significant issue. Much of the elbow and shoulder injuries sustained by the pre-adolescent baseball athlete are overuse injuries that may be avoided with proper training and exercise interventions.

The number of reported injuries in baseball has continued to rise throughout all levels of competition. In particular we are seeing a larger number of injuries in the youth population than previously. Conte et al. acknowledged that up to 74% of players ages (8-18) report arm pain while throwing with about 25% consistent with overuse.

Medical professionals have done a good job at establishing potential risk factors for injury and have implemented guidelines for youth players and associated personnel to follow. However, little has been documented with regards to preventative arm care programs for the youth population. In an effort to reduce the likelihood of injuries related to overuse the American Sports Medicine Institute provides recommendations regarding risk-prone pitching activities to help reduce the likelihood of injuries related to overuse. These recommendations include (1) no competitive baseball pitching for at least 4 months per year, (2) following limits for pitch counts and rest days, (3) avoiding pitching on multiple teams with overlapping seasons, (4) not playing both catcher and pitcher, (5) playing other sports in addition to baseball, and (6) discontinuing pitching if the pitcher reports pain in the shoulder or elbow.

Compared to the elite level professional, the youth athlete has unique characteristics, which may alter the way in which arm care programs are developed. These individuals are skeletally immature and often present with reduced core strength, hip strength, posterior chain strength, compromised single leg balance, coordination and scapular dyskinesia. Sakata et al. identified increased risk of medial elbow injury with pitching in those with increased thoracic kyphosis and deficits in elbow extension. Previous prospective studies reported altered shoulder range of motion, posterior shoulder tightness, rotator cuff weakness, scapular dysfunction, lower extremity muscle tightness, and deficits in single leg standing balance, as physical risk factors associated with throwing injuries of the shoulder and elbow.

The purpose of this manuscript is to discuss the risk factors of injuries in the youth baseball player and to describe a modification of the Thrower’s Ten exercise program that addresses the unique characteristics of the youth baseball player.

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RISK FACTORS

The overhead athlete, particularly overhand pitchers, are at risk for injury due to the aggressive demands of throwing. Throwing, specifically the late cocking and acceleration phase of the pitch, from fully externally rotated cocking to early acceleration in the adult elite thrower, is the fastest functional movement recorded. The internal rotation movement is produced in 0.05 seconds at angular velocities of 7,250 degrees per second, resulting in anterior shear and distraction forces across the glenohumeral joint of 0.5 times, 1.5 times that of the throwers body weight respectively. While strenuous on the entire body, it is for these reasons that much of the injuries seen in throwers manifest themselves in the shoulder or elbow.9

Lyman et al.10 performed a longitudinal study following youth baseball players ages 9 to 12 years old over the course of 2 consecutive seasons. The authors reported older individuals with increased weight and decreased height were at higher risk for injury. Additionally, those who lifted weights, pitched outside of little league (such as during showcase events), and reported decreased self-satisfaction with performance were also at an increased risk. Interesting to note they were able to correlate that there was a 1.5% increased risk of shoulder pain with each pitch thrown, however for every 10 pitches thrown in game there was a 6% increase odds of elbow pain with significant trends per 25 pitches. Based on these findings they suggest that a pitch count limit be implemented for 75 pitches, because those who exceeded this count were at 3.2x more likelihood of experiencing shoulder pain.

Following this study Olsen & Fleisig11 reported additional risk factors associated with overhand pitching in the youth population. The study suggests that the primary risk factors for these individuals was pitching with arm fatigue (56x increased risk), over use (80+ pitches per game (increased 4-fold), 8+ months per year (increased 5-fold), starting pitching, showcases or playing outside of little league, 100+ innings pitched) and velocity (85mph+ with 2.58 times risk). Additionally, individuals who were (4cm) taller and (5kg) heavier for their age group were at higher risk of injury and special attention should take place. The authors’ primary suggestion was the importance of long-term health education for all members assisting to care for the individual. The individuals should incorporate an active warm up that includes arm care and aerobic conditioning, not just throwing. They should avoid pitching 80+ pitches per game, 2,500 pitches per year, 8 or more months per year. Lastly, they acknowledge that those under the age of 13 should avoid breaking pitches.

Other studies report the loss in glenohumeral proprioception up to 78% during fatigued throwing.12 Thus an arm care program can be designed to improve endurance and strength of the upper extremity but should encompass the entire body to aid in injury prevention.

The principle predictive risk factor for injury in the overhead athlete is throwing while fatigued. This is supported at the elite, professional level in a study conducted by Murray et al.13 This group documented effects that occur throughout the body such as decreased shoulder external rotation, shoulder adduction torque, and lower extremity knee flex-

ion which in turn led to diminished ball velocity. Despite this documentation Makni et al. reported in a survey that 46% of athletes were encouraged to continue playing with arm pain.14

In a national study of 754 pitchers Fleisig, Yang et al.15 found that; 69.2% reported pitching with arm tiredness, 37.9% with arm pain, 43.5% pitched on consecutive days leading to 4 times greater risk for experiencing tiredness and 2.5 times greater risk for pain, 30% of which pitched for multiple teams with overlapping seasons regardless of the 3 times increased risk of tiredness compared with those who pitched for 1 team, and 20% pitched in multiple games in one day which led to 89% greater odds of experiencing arm pain.

While risk factors for overuse are clearly established, there continues to remain a disconnect between players, coaches, parents and personnel; further stressing the importance of medical education.

PREVENTION PROGRAM

As stated previously the literature concludes that arm care programs are essential to the overhead athlete. However, there is little documentation with regards to specific programming for the youth athlete. Sakata et al.16 aimed to study the efficacy of a prevention program in youth baseball players. The author’s analyzed risk for medial elbow injury in males and females ages 9 to 12 who played either pitcher, another position or both. Based on their findings; total shoulder rotational motion, hip internal rotation range of motion, and thoracic kyphosis angle were the primary modifiable risk factors for medial elbow injury. They created a program consisting of 9 stretching and 9 strengthening exercises aimed to improve these areas. 305 (male and female) players, ages 8 to 11 were included with 136 allocated to the intervention group and 169 for the control. The intervention group performed their program at a minimum of once per week and both groups followed up with physicians every 3 months. Results indicate a significantly lower incidence rate of medial elbow injury, improved total range of shoulder rotation (dominant side), hip internal rotation (nondominant side), shoulder internal rotation deficit (bilateral), lower trapezius muscle strength (dominant side) and thoracic kyphosis angle. These results, while promising, do not analyze a homogenous population which led the authors to develop a program of their own.

The Thrower’s Ten Program, established by Wilk et al.17, is an evidence-based exercise program for the overhead athlete. This program utilizes isometric movements that are derived from electromyographic research to specifically address vital muscles involved in the throwing motion. In 2011 Escamilla et al.18, reported that participating in this program for 6 weeks enhanced athletic performance by indicating approximately 2% increase in ball velocity. While the documented results are beneficial, they are indicated for an older population.

A recent clinical consensus by Matsel et al.19 suggests that youth overhead throwers should participate in an arm care program that addresses the entire kinetic chain through a multiphasic approach. This article presents a variation of the Throwers Ten Exercise Program, which has
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been utilized with excellent results in clinical practice and athletic performance training. The purpose is to incorporate the entire kinetic chain in a simple, easy to follow manner, to prepare the youth population for the demands of overhead activity.

The Youth Throwers Ten Exercise Program outlined in this article contains alterations to a previously outlined Throwers Ten Exercise Program by Wilk et al. This new program emphasizes technique and movement awareness, where individuals will frequently be cued to maintain a posteriorly tilted, externally rotated, and retracted scapula. All exercises performed involve the use of body weight or a single piece of theraband and thus can be performed by all individuals. The individual is instructed to perform 2 sets of 10 repetitions for each exercise with minimal to no rest between movements.

The Youth Throwers Ten Exercise Program begins with IR and ER theraband exercises at 0 degrees of abduction with a towel roll between the individual's arm and side. Reinoel et al. documented greater electromyographic activity of the posterior cuff musculature when the towel roll is used. The idea is that the shoulder will be placed into slight abduction and the authors suggest that if a player does not have a towel that they substitute with the use of their glove.

Next is the full-can from a split stance lunge (Figure 1). The exercise set up begins with the individual in half kneeling with a piece of theraband under their lead leg with the ends in each hand by their sides. They are next instructed to partially stand up holding an isometric lunge position, maintaining 90-degree hip and knee flexion angles in their lead leg, neutral extension with 90-degree knee flexion angle in their trail leg, upright posture and scapula positioning as previously described. While holding this position, they are instructed to raise both arms, with straight elbows and thumbs pointed upward, to shoulder height at 30-degree angles holding for 2 seconds at the apex of the movement and slowly lowering to the starting position. To perform the second set the athlete will switch their footing such that their lead leg in the first set will now be their trail leg in the second, and vice versa. The purpose of the sustained split stance lunge position is to elicit activation of the entire kinetic chain, particularly the gluteus medius; which is reported to have high activity during early acceleration and ball release.

This is followed by shoulder abduction to 90 degrees from a split stance lunge. This will be performed in the set up described for the full-can but the individual will raise their arms to shoulder height, with elbows extended and palms facing down. If the individual does not have access to a theraband they can use their glove, a baseball or a combination of the two for resistance.

Side-lying ER is performed with a theraband under the floor-side arm and may be progressed to a modified (kneebent) or standard side plank position to challenge the athlete (Figure 2). Caution must take place to ensure that the athlete has the dynamic stability required to support the weight of their body and perform the task with neutral spine alignment.

The following three exercises are all to be performed while standing in a partial squat position. The athlete should flex at the hips and knees to 90 degrees, maintaining an upright trunk with scapula posteriorly tilted, externally rotated and retracted to improve coordination between the muscles of lumbo-pelvic hip complex and scapula musculature. The theraband should be anchored to the backstop fence or held by a partner. The first of three exercises is low rowing (Figure 3), followed by the modified robbery (Figure 4), and a high row at 90 degrees abduction into 90 degrees of external rotation. These exercises aim to enhance scapula neuromuscular control via synchronicity of muscle firing for scapulothoracic musculature. A lack of scapular muscle synchronicity, particularly of the lower and middle trapezius, is a key factor in overhead athletes with shoulder pain. To address the remainder of the upper extremity and protect the individual from the inherent stresses on the elbow joint during the throwing motion, elbow strengthening exercises such as biceps curls, triceps extensions, and wrist/forearm four-ways (flexion, extension, pronation, supination) with theraband to be performed.

The final two exercises aim to address the entire kinetic chain, specifically the diminished lower extremity neuromuscular coordination and reduced core strength commonly seen in the youth athlete. The single leg squat or front-step down (Figure 5) is an exercise that doubles as a clinical exam used to assess balance, coordination, neuromuscular control and strength.

Common faults seen with this task are trunk lean (torso outside of the individual's base of support), dynamic knee valgus "wiggle-wobble" and excessive pronation. The coach or supervisor should be aware and able to correct or cue the individual performing the task out of these positions. Lastly the athlete is to perform a lateral slide with theraband (Figure 6) which has high electromyographic activity for gluteus medius. The theraband is to be placed around the individual's knees and progressed towards the feet as they gain strength. The athlete should be instructed to perform a partial squat position and side step slowly, keeping tension on the band and the height of the squat.

SUMMARY

Overhead throwing is a physically demanding task and typically leads to upper extremity injuries. In recent years there has been a rise in the frequency and likeliness of these injuries. It is imperative that coaches, parents and youth are educated on ways to safely, efficiently and effectively train for the demands of their activity. The Youth Throwers Ten Program presented in this article provides a framework for these individuals to properly prepare for competition.

Submitted: October 01, 2021 CST, Accepted: November 07, 2021 CST
<table>
<thead>
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<th>Exercise Program</th>
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<td>• IR/ER tubing at 0 degrees of abduction</td>
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<tr>
<td>• Split-stance lunge</td>
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<tr>
<td>◦ Full Can</td>
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<td>◦ Lateral raise to 90 degrees of abduction</td>
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<td>• Side-lying external rotation (modified side plank)</td>
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<td>• Squat stance</td>
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<tr>
<td>◦ Low row</td>
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<td>◦ Modified robbery</td>
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<td>◦ High row, external rotation (90-90)</td>
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<tr>
<td>• Biceps Curl</td>
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<td>• Triceps Extension</td>
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<td>• Wrist flexion</td>
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<td>• Wrist extension</td>
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<td>• Forearm pronation</td>
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<tr>
<td>• Forearm supination</td>
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<tr>
<td>• Single leg squat / front step-down</td>
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<td>• Lateral slides</td>
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</table>

Figure 1. Standing full can exercise performed with a resistance band and in a split squat position. This position promotes legs & hips activation.
Figure 2. Sidelying external rotation strengthening being performed in a side plank position to recruit hips & core muscles.

Figure 3. Standing shoulder complex rowing using resistance bands while in a partial squat position to activate legs & hip muscles.
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Figure 4. Modified robbery exercise utilizing resistance bands in a partial squat position.

Figure 5. Single leg squat to strengthen the leg but also lateral hip musculature.
Figure 6. Lateral slides with a resistance band to provide resistance to the lateral hip musculature.
REFERENCES


Umbrella Review

Lower Limb Exercise-Based Injury Prevention Programs Are Effective in Improving Sprint Speed, Jumping, Agility and Balance: an Umbrella Review

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Keywords: systematic review, performance, prevention programs, lower limb injury, exercise

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Background

Exercise-based injury prevention programs for athletes have demonstrated consistent results in reducing the risk of lower limb injuries. Compliance is essential for program effectiveness and may be facilitated when these programs demonstrate positive effects on athletic performance.

Hypothesis/Purpose

To summarize the findings of current systematic reviews on the effectiveness of lower limb injury prevention programs with multiple neuromuscular components on sports performance and quantify these effects. The authors hypothesized that injury prevention programs can improve certain sports performance criteria.

Study Design

Umbrella systematic review

Methods

Systematic reviews published in French, German, or English between January 1990 and January 2020 were identified in five databases. Only articles that investigated multicomponent lower limb injury prevention programs and their effects on the performance criteria of strength, balance, agility, jumping or speed by both amateur and professional athletes of all ages and sex were included. The methodological quality of the included systematic reviews was assessed by two reviewers independently using the Assessing the Methodological Quality of Systematic Reviews measurement tool.

Results

Five systematic reviews met the inclusion criteria. Overall, beneficial effects of multicomponent exercise-based injury prevention programs were observed for balance, agility, jumping and speed. While the effects on strength were more variable, there was a positive trend in favor of injury prevention programs.

Conclusion

Injury prevention programs with multiple neuromuscular exercise components demonstrate overall beneficial effects on the performance criteria of balance, agility, jumping or speed. These beneficial effects may be used to promote the implementation of such programs.

Level of Evidence

2a

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INTRODUCTION

Physical activity is an important component of good health for all individuals and recommended for improving cardiorespiratory and muscular capacity, bone health and reducing the risk of depression and non-communicable diseases. However, participation in recreational or competitive sports is not without an increased risk of acute injury or overload. Many interventions have been developed to reduce the risk of sports-related injuries, especially at the lower limb. In particular, prevention programs composed of several neuromuscular training components such as muscle strengthening, balance and agility training have demonstrated preventive effects for lower limb injuries. While these programs have around 39% efficacy in reducing the risk of lower extremity injury and even higher efficacies of 54% and 50% for acute knee injuries and ankle sprains respectively, the effects may vary.

Compliance with injury prevention programs plays a key role in achieving the greatest possible preventive effect. To increase compliance, it has been suggested that the coach is the most important person to promote the process of implementing an injury prevention program and regular practice of these programs is also required to achieve the desired outcome. Yet a coach can more easily be persuaded when a better understanding of the motivations and facilitators behind program implementation is attained. From the trainer’s perspective, one of the key factors in sport is performance; the implementation of prevention programs could be facilitated if these protocols were to demonstrate positive effects on performance. In fact, performance is identified as the primary goal of elite sport by coaches as well as athletes and sport physiotherapists. Athletic performance is defined as the ability to respond effectively to the specific physical demands of the sport being played. Several performance factors include maximum muscle strength and muscle power, agility, speed, flexibility, balance and stability. Furthermore, injury prevention is defined as an accessory goal in achieving athletic performance.

The effects of injury prevention programs on performance must be clearly understood to facilitate the primary implementation of these programs by coaches. Therefore, our study objectives were to summarize the findings of current systematic reviews on the effectiveness of lower limb injury prevention programs with multiple neuromuscular components on sports performance and to quantify their effects. We hypothesized that injury prevention programs can improve certain performance criteria.

METHODS

This umbrella review was carried out according to the model of Aromataris et al. Details of the review protocol are registered on PROSPERO and can be accessed at https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42020162334.

SEARCH METHODOLOGY

For this umbrella review, two authors compiled all evidence from pertinent systematic reviews found within the following databases: PubMed, CINAHL, Ovid, Cochrane Database of Systematic Reviews, and PEDro. The search strategy was guided using the Population Intervention Comparison Outcome Study Design (PICOS) approach and selected terms were combined in a Boolean search. Key terms used were "sportsman", "sportswoman", "injury prevention program" and "performance". More details about the search strategy used and the results for every database can be found in Appendix 1.

All systematic reviews had to be written in French, German or English and published between January 1, 1990 and January 31, 2020. Thereafter, a sports injury prevention expert/co-author identified any further references relevant to the topic, which had not been identified by the initial search strategy and to ensure comprehensive coverage of the literature.

All identified references were imported into the Covidence systematic review software (www.covidence.org) (Veritas Health Innovation, Melbourne, Australia) to identify and remove duplicates. Two authors then independently screened all article titles and abstracts to select relevant reviews eligible for full-text reading. The inclusion criteria were defined as follows:

Population: athletes of all ages and sex who participate in any sport (e.g. soccer, basketball, volleyball, ice hockey)

Intervention: all types of multicomponent exercise intervention (e.g. strength, balance, plyometrics...) used with the goal to prevent injuries of the lower limb

Comparison: usual training and/or usual warm-up procedures

Outcomes: performance criteria defined as: (1) strength, (2) balance, (3) agility, (4) jumping ability, or (5) speed.

Exclusion criteria were defined as not meeting one or more of the defined inclusion criteria. If there was any doubt about the eligibility of a screened reference, consensus was reached primarily by discussion and a third author was only consulted when the reference's eligibility could not be established.

METHODOLOGICAL QUALITY ASSESSMENT

The Assessing the Methodological Quality of Systematic Reviews (AMSTAR) tool was used to classify the reviews according to their methodological quality. Eleven items are assessed using the options of "yes", "no", "not applicable" and "cannot answer", where single points on the AMSTAR scale can only be accumulated for each "yes" answer. The AMSTAR ranking is based on three categories indicating low quality reviews with scores of 0 to 3 points and reviews of moderate (4 to 7 points) and high quality (8 to 11 points). Two authors independently assessed the methodological quality of the included systematic reviews according to AMSTAR and only those of moderate or high quality were included, as summarized in Table 1. Any AMSTAR rating conflicts were resolved by discussion with a third author until consensus was reached.
DATA EXTRACTION AND ANALYSIS

The data extraction process was carried out independently by two authors. Information on the author, publication year, sample size, intervention and study outcomes was collated and managed in Microsoft Excel 2020. For any conflicting data, a third author was consulted until consensus was reached.

The outcomes analyzed for this umbrella review included the following performance measures: strength (quadriceps and hamstring isokinetic strength and hamstring/quadriceps ratios), balance (ability to maintain one’s center of gravity within their base of support), agility (ability to change direction), jumping abilities (horizontal and vertical jumping as well as reactive jumping [e.g. drop jumping]) and sprint speed (in a straight line). Further data on the number of study participants, sex of the study population, and type of sport participated in were also exported. If a meta-analysis was conducted within the systematic review, the results of the studies were reported using the standardized mean difference (SMD), 95% confidence interval (95% CI) and I² test. When the SMD was not reported, other measures including either the mean difference (MD) or percentage of change from baseline were noted as available. When a meta-analysis was not performed, a narrative synthesis of the study results—describing the findings of the included studies based on outcomes and intervention types executed—was provided.

For all meta-analyses, effect sizes were categorized according to Cohen’s as follows: values of 0 to 0.19 indicate a negligible effect, 0.20 to 0.49 represents a small effect, 0.50 to 0.79 a moderate effect, and greater than 0.80 a large effect.

Based on the umbrella review guidelines, a “traffic lights” system was used to summarize the effectiveness of prevention programs on the various performance criteria selected. A red color indicates that the intervention may be detrimental or less effective than the comparator (i.e. normal training program). An orange color was set for reviewed studies showing no difference between the comparison and intervention, and green denoted any beneficial effect of the intervention.

RESULTS

A total of 4,816 studies were initially identified with an additional reference discovered by the injury prevention expert (Figure 1).

After the removal of all duplicates, 4,012 abstracts and article titles were screened, and 4,004 references were excluded after reading the titles and abstracts. The full text of the remaining eight references was read and two studies were excluded because they did not meet the inclusion criteria. The methodological quality of the remaining six studies was assessed, which resulted in the exclusion of one study due to its low methodological quality (AMSTAR score ≤ 3). The overall methodological quality of the final reference selection—comprising five systematic reviews that assessed the quality of 61 primary studies—as summarized in Table 1.

Figure 1. PRISMA Diagram

INJURY PREVENTION PROGRAMS

A comprehensive summary of the review findings outlining the effects of injury prevention exercises on the selected performance criteria is detailed in Appendix 2.

EFFECTS ON STRENGTH

Of the five systematic reviews, four evaluated the effect of neuromuscular exercise programs aimed at reducing the risk of injury on strength. For hamstrings, small to moderate improvements were reported for isokinetic speeds of 60°/s (SMD: 0.56) and 240°/s (SMD: 0.31). Another review found an improvement in hamstring strength when interventions included eccentric hamstring strengthening exercises. Yet only small to negligible effects were observed in favor of improving quadriceps strength at isokinetic velocities of 60°/s (SMD: 0.49) and 240°/s (SMD: 0.19). The group of ter Stege reviewed studies focused on overall strength of the lower limb and found an improvement in the strength of the entire lower limb.

For hamstring–quadriceps ratios, a small positive effect was noted only at an isokinetic velocity of 60°/s (SMD: 0.40) with negligible effects at 240°/s (SMD: 0.13). The effects of interventions on hamstring–quadriceps force ratios were variable, but an 11.3% improvement in strength in favor of prevention programs was reported.

EFFECTS ON BALANCE

Four reviews evaluated the effects of prevention programs on balance. A small positive effect (SMD: 0.29) was noted for static balance. For dynamic balance, the effects were also positive but variable: one review found a small effect (SMD: 0.51), another found a large effect size (MD: 2.68) and a third review reported the overall effectiveness of interventions on balance with an average improvement of 5.2% in scores between the baseline and post-intervention time points. The fourth review highlighted the variability in outcomes, but noted that dynamic balance can be improved in both groups; there was no improvement in dy-
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Table 1. Methodological quality assessment of systematic reviews using AMSTAR.

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<td>Was the methodological quality of the included studies evaluated and documented?</td>
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<td>Was the specific quality of the included studies used appropriately in formulating conclusions?</td>
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<td>Were the methods used to combine the findings of studies appropriate?</td>
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<td>Yes</td>
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<td>Were the conflicts of interest stated?</td>
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</table>

Total AMSTAR score | 3/11 | 9/11 | 7/11 | 7/11 | 7/11 | 5/11 |

N/A = not applicable, CA = can’t answer

Dynamic balance in the pediatric group. For dynamic stability, moderate effects were observed (SMD: 0.72).29

EFFECTS ON AGILITY, JUMPING AND SPEED

Two reviews identified large (SMD: 0.88) as well as weak effects (SMD: 0.25) in favor of prevention programs on agility.29,30

Two reviews identified the effects of prevention programs on vertical jumping and demonstrated small (SMD: 0.3129 and 0.2430), yet overall effectiveness of interventions on this outcome. For reactive jumping, weak effects (SMD: 0.29) were seen and for the horizontal jumping, there were negligible effects in favor of implementing prevention programs (SMD: 0.04).29 Three reviews evaluated the effects of prevention programs on speed. There were moderate effects of prevention programs (SMD: 0.66) on sprint speed,29 although another review only found a weak effect (SMD: 0.56).31 As a result of injury prevention programs in youth athletes, Hanlon et al.31 only found a 2.2% improvement in speed,31 whereas an earlier review also focused on youth sports observed a large effect in favor of such programs (SMD: 0.92).29

DISCUSSION

The results of this umbrella review showed that there were five systematic reviews of moderate to high quality that examined the effects of lower extremity injury prevention programs on the performance outcomes analyzed. While the results for strength were quite variable, there was a trend indicating small to moderate improvements in this performance parameter as a result of prevention exercises. For the performance criteria of balance, agility, jumping and speed, the reviews demonstrated the clinical efficacy of prevention programs over control interventions. It is important to note that we considered prevention programs as effective for speed based on the systematic review of Hanlon et al.31 and the clinical effect observed. Nevertheless, it is necessary to interpret this result with caution due to the lack of reported confidence intervals.

Not all performance outcomes were collectively targeted in any one of the five systematic reviews included in this analysis. Strength was analyzed in four systematic reviews29,31–33 covering 22 unique primary studies, which is the largest number of primary studies for any one of the outcomes studied. The parameters of balance, agility, jumping and speed were evaluated by fifteen, nine, ten and eleven unique primary studies, respectively. Furthermore, many of the primary studies were included in more than one review among the selected articles. This could have an influence on the results of this umbrella review.

This work provides a synthesis of the effects of lower extremity injury prevention programs on performance in sport populations. These elements allow the clinician to make more informed choices when implementing such strategies. While the results demonstrate the overall ef-
fectiveness of prevention programs for sport performance, caution should be applied when interpreting the results because the efficacy of an intervention is defined in terms of its clinical significance and not only its statistical significance. The analyzed studies revealed vast heterogeneity among the populations that practiced a wide range of sports including soccer, floor hockey, futsal, volleyball or basketball. This may be due to selection bias, since we included studies covering a wide range of sporting populations of varying age, sex and playing level. The risk of publication bias also exists and while studies showing a statistically significant effect are more likely to be published, this aspect may play a role in the interpretation of the study results. A third important element is the study protocol variability; in fact, the length of implementation and frequency in practicing each of the different prevention programs was highly diverse. Consequently, performance bias may play a role in the analysis, but should be partially limited because the main outcomes of performance are objective measures. Furthermore, compliance was not comprehensively reported for all the included reviews and thus, could not be adequately presented within this umbrella review. Indeed, when studied, injury prevention program compliance is known to largely influence the outcome of the intervention (report bias). Additionally, current research suggests that adherence (proactive behavior) may be a more appropriate measure than compliance (passive behavior) when implementing exercise interventions. As noted by Brunner et al., further studies should consider the systematic documentation of specific information such as the target population, details of performed drills with focus on intensity, frequency, type of exercise and duration, and a description of program implementation. Only through systematic documentation can data reproducibility be ensured for consistency when interpreting the reported results.

Further research should attempt to investigate some of the less studied outcomes such as agility or jumping, to better understand the potential improvements when practicing prevention programs. A second opportunity would be to study the effects of the different components (e.g. plyometrics and strength training) of the prevention programs separately. Understanding the individual effects of these components on performance and prevention would make it possible to (1) adapt these preventive programs to a specific sport context and (2) target certain determining aspects of sport performance in this context. The ultimate goal would be to encourage coaches to adhere to these programs as well as encourage athletes to regularly comply with them in an assiduous manner.

CONCLUSION

Injury prevention programs with multiple neuromuscular exercise components demonstrate overall efficacy to improve balance, agility, jumping and speed. For strength, the effects are varied, yet show a positive trend towards the usefulness of prevention programs. These beneficial effects on performance, coupled with demonstrated effectiveness in injury prevention, can be used as evidence for coaches to promote their implementation on a regular and consistent basis.

CONFLICT OF INTEREST

None of the authors have any conflicts of interest pertinent to this manuscript to disclose.

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REFERENCES


SUPPLEMENTARY MATERIALS

Appendix 1

Appendix 2
Single-Leg Vertical Hop Test Detects Greater Limb Asymmetries Than Horizontal Hop Tests After Anterior Cruciate Ligament Reconstruction in NCAA Division 1 Collegiate Athletes

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Keywords: hop testing, return to sport, rehabilitation, acl reconstruction, anterior cruciate ligament, movement system

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Background
Knee function deficits may persist after anterior cruciate ligament reconstruction (ACLR). Return to sport (RTS) testing batteries assess recovery after ACLR and can guide RTS progression, but the ideal test components are debatable. The single leg vertical hop for height (SLVH) test using a commercially available jump mat may provide a valuable assessment of knee function.

Hypothesis/Purpose
The purpose of this study was to compare the limb symmetry index (LSI) of SLVH to horizontal hop testing in a cohort of National Collegiate Athletic Association (NCAA) Division 1 collegiate athletes after ACLR. The hypothesis was the SLVH would elicit significantly lower LSI than horizontal hop tests.

Study design
Cross-Sectional Study

Methods
Eighteen National Collegiate Athletic Association (NCAA) Division 1 collegiate athletes (7 males, 11 females) at 7.33 ± 2.05 months after ACLR were included in this retrospective study. LSI was calculated for single hop for distance (SHD), triple hop for distance (THD), cross-over hop for distance (CHD), timed 6-meter hop (T6H), and SLVH. A repeated measures ANOVA was performed to identify differences in LSI for each test. Spearman’s Rho correlation coefficient was calculated to examine the relationship between LSIs for each test.

Results
The LSI for SLVH (84.48% ± 11.41%) was significantly lower than LSI for SHD (95.48 ± 8.02%, p = 0.003), THD (94.40 ± 3.70%, p = 0.002), CHD (95.85 ± 7.00, p = 0.007), and T6H (97.69 ± 6.60%, p = 0.001). The correlation of LSI between SLVH and the horizontal hop tests was weak and non-significant for SHD (rₛ = 0.166, p = 0.509), CHD (rₛ = 0.199, p = 0.428), and T6H (rₛ = 0.211, p = 0.401) and moderate and non-significant for THD (rₛ =
0.405, p = 0.096).

Conclusions
Individuals after ACLR had lower LSI on the SLVH than on horizontal hop tests and weak to moderate correlations between the tests suggest SLVH detects performance deficits not identified by the horizontal hop tests.

Level of evidence
3

INTRODUCTION
Over 120,000 anterior cruciate ligament (ACL) tears per year occur in the United States.1 In athletes, the majority of these tears are addressed with ACL reconstruction (ACLR) surgery.2 Post-operatively, rehabilitation is crucial to restore function and promote a safe return to activities of daily living and sport. Despite current rehabilitation standards and return to sport criteria, outcomes still may not be optimal. A systematic review of prospective studies that followed patients for at least five years post-surgery reported in the pooled data that 5.8% of ipsilateral ACLR autografts failed and 11.8% of patients had an ACL tear in the contralateral limb.3 Arden et al. reported pooled return to sport rates of 74% to 87%, however, only 59% to 72% of patients returned to their preinjury sport, and only 46% to 63% returned to competitive sports.4 Level of play is an important variable to consider after ACLR as it may help discern whether athletes are not doing as well as originally thought.5,6 Return to sport (RTS) testing batteries are used by sports medicine and rehabilitation professionals to measure outcomes and provide guidelines for clinical decision making during the RTS progression.7–12 They may be a helpful component of the return to sport process and ultimately improve outcomes by identifying athletes in need of continued rehabilitation. Traditional horizontal hop testing that measures the distance one can hop forward is a commonly used component of these batteries.7,13 These tests include a number of hopping tasks that assess either the distance one can hop in single or multiple unilateral jumps, or the time it takes an individual to hop on the impaired limb a specified distance. However, all of these tests assess hopping in a primarily forward direction. In contrast, the single leg vertical hop for height (SLVH) test measures the height that one can hop upward and is emerging as a useful assessment of knee function after ACLR.14–17 This is because the SLVH test relies more heavily on the power generated by the quadriceps to create a vertical impulse than the traditional horizontal hop tests.15,18 Achieving > 90% limb symmetry index (LSI), a value comparing the performance on the involved to the uninvolved limb, is often advocated as a marker of successful rehabilitation.10,11,19 A benefit of hop testing is that it is easy to perform in the clinic and has demonstrated appropriate reliability and validity to use after ACLR.20 Other common tests/measures include measurements of strength, power, graft integrity, movement quality, psychological readiness, and patient reported outcomes.5,9,15,21–27 However, controversy exists over the ideal combination of tests to use, if results on these tests are associated with better outcomes, and how these tests assess knee function.23,28–34 This conflicting information poses challenges to sports medicine and rehabilitation professionals when considering how to objectively guide RTS decision making.35 Further exploration of RTS testing options will allow clinicians to better select outcome measures that assess relevant components of knee function.36,37 The SLVH test is easy to administer and may provide helpful information regarding knee function after ACLR.14,15,33 Taylor et al. found greater LSI asymmetries on the SLVH compared to horizontal hop tests and poor correlation between SLVH and the horizontal hop tests, suggesting that SLVH may measure constructs that horizontal tests cannot.16 While promising, that study had wide inclusion criteria that analyzed individuals many years (4.7 ± 2.6) after surgery and used 3D motion capture and force plate assessment, which may not be applicable to traditional rehabilitation settings. Exploration of SLVH performance earlier after ACLR through the lens of clinical practice and may help guide clinical decision making during the later stages of rehabilitation. The purpose of this study was to compare the LSI of SLVH to horizontal hop testing in a cohort of National Collegiate Athletic Association (NCAA) Division 1 collegiate athletes after ACLR. It was hypothesized that the SLVH would elicit significantly lower LSI than the horizontal hopping tests and provide unique information from the horizontal hopping tests to be used in clinical decision making after ACLR.

METHODS
PARTICIPANTS
A retrospective review was conducted to examine a consecutive series of patients between August 2018- November 2020 who met the inclusion criteria of NCAA Division 1 collegiate athletes referred to the University of Maryland Sports Medicine practice to assess their recovery after unilateral ACLR. Patients were excluded from the study for 1) a history of prior ACLR to either knee or 2) any other lower extremity musculoskeletal surgery within the previous two years. To determine sample size, an a priori power analysis was conducted based on the work of Taylor et al.16 A sample size of 14 was required to detect an effect size of 0.8 for the primary outcome measure, limb symmetry index (LSI), with α =0.05 and a power (1−β) = 0.80. The Institutional Review Board at the University of Maryland, Baltimore determined this study to be exempt.

PROCEDURES
The necessary demographic and hop testing data were ex-
trated and de-identified from subjects' electronic medical records. Demographic data is included in Table 1. Hop testing data collected included limb symmetry indices (LSIs) for a battery of single leg hop tests including: single hop for distance (SHD), triple hop for distance (THD), cross-over hop for distance (CHD), timed 6-meter hop (T6H), and single leg vertical hop for height (SLVH). Data were collected as part of usual clinical practice by physical therapists (authors MZ or RR) who are board-certified in either sports or orthopedic physical therapy and each have over eight years of experience working with patients with ACL injuries.

Testing procedures were based upon previously published instructions and included a warmup, two practice trials, and two test trials; the two test trials were averaged for the final result for each test which was used for statistical analysis.\(^7,8,14\) Horizontal hop tests (SHD, THD, and CHD) were performed over ground and measured with a tape measure. The T6H was performed over ground and measured with a standard timer on a smart phone device. The SLVH was performed on the Just Jump System (JJS, Probotics Inc, Huntsville, AL, USA), which is a commercially available jump mat that calculates jump height from flight time between foot contacts and is valid when compared to three-dimensional camera motion capture.\(^38\)

For the SHD, the instructions were to hop as far forward as possible and hold the landing on the testing leg for two seconds. For the THD and CHD, participants were instructed to perform three continuous forward hops and hold the final landing on the testing leg for two seconds. For the T6H, the instructions were to hop on the testing leg as fast as possible down a 6-meter course, with the time needed to complete the course recorded for analysis. For the SLVH (Figure 1), the instructions were to perform a countermovement, single leg vertical hop as high as possible and hold the landing on the testing leg for two seconds. The patients were also instructed not to excessively flex their hips while in the air to prevent artificially increasing flight time but were allowed to use their arms. Limb symmetry indices (LSIs) were calculated by dividing the result on the involved limb by the result on the uninvolved limb and multiplying by 100 to produce a percentage. For the T6H, the numerator and denominator were reversed in the calculation, as a lower time indicates better performance. Therefore, for all tests, a value less than 100% indicates a worse performance on the surgical limb compared to the non-surgical.

STATISTICAL ANALYSIS

Descriptive statistics (means and standard deviations) were calculated for all dependent variables. Shapiro-Wilk test was used to assess the normality of the LSI data for each hop test. Repeated measures ANOVAs (within-subject factor: test) were performed to identify differences in LSI across the tests. Post-hoc analysis was conducted when significant main effects were found to evaluate pairwise comparisons for LSI between specific tests. As the Shapiro-Wilk test determined that the LSI for two of the five tests was not normally distributed, non-parametric Spearman's Rho correlation coefficient was used to examine the relationship between limb symmetry index for each test. Additionally, this test has been reported to be more robust to outliers than the traditional Pearson correlation coefficient.\(^39\) All statistical analyses were performed using SPSS version 27 (IBM Corp.) with \(p \leq 0.05\) indicating statistically significant differences.

RESULTS

A total of 18 patients (7 males, 11 females) with an average age of 20.39 ± 1.11 years were included (Table 1). Sports played by patients are presented in Table 2. Data was not analyzed by sport, but this information helps characterize the sample. All patients had undergone primary ACLR with bone-patellar tendon-bone autograft and were an average of 7.33 ± 2.05 months since surgery.

There was a difference in LSI across the hop tests, with a significant main effect of hop test on the LSI (\(F(4,14)=5.549, p = 0.007\)) seen across the participants (Figure 2). Post-hoc pairwise comparisons show that the LSI for SLVH (84.48% ± 11.41%) was significantly lower than the LSI calculated for each of the horizontal hop tests: SHD (95.48 ± 8.02%, \(p = 0.003\), THD (94.40 ± 3.70%, \(p = 0.002\)), CHD (95.85 ± 7.00, \(p = 0.007\)), and T6H (97.69 ± 6.60%, \(p = 0.001\)).

Fourteen patients (77.78%) scored > 90% on all four horizontal hop tests. In contrast, only six patients (33.33%) scored > 90% on the SLVH. Of the fourteen patients who scored > 90% on all four horizontal hop tests, only five patients (35.71%) scored > 90% on the SLVH. None of the five patients who scored ≤ 90% on the horizontal hop tests scored > 90% on the SLVH.

There were no statistically significant correlations observed between the LSI for the SLVH to the other four tests (Figure 3). Overall, there were weak correlations between the limb symmetry indices for the SLVH to the SHD (\(r_s = 0.166, p = 0.509\)), CHD (\(r_s = 0.199, p = 0.428\)), and T6H (\(r_s = 0.211, p = 0.401\)) and a moderate correlation when comparing the SLVH to the THD (\(r_s = 0.405, p = 0.096\)).

DISCUSSION

The aim of this study was to compare LSI calculated from the SLVH to four horizontal hop tests after ACLR. The main findings supported the hypothesis that LSI of the SLVH test would be significantly lower than all horizontal hop tests.

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**Table 1. Patient demographics**

<table>
<thead>
<tr>
<th>Demographic variable</th>
<th>All (n=18)</th>
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<tr>
<td>Male: Number (%)</td>
<td>7 (39%)</td>
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<td>Female: Number (%)</td>
<td>11 (61%)</td>
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<tr>
<td>Age, years</td>
<td>20.39 ± 1.11</td>
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<td>Height, meters</td>
<td>1.75 ± 0.09</td>
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<tr>
<td>Weight, kilograms</td>
<td>75.61 ± 15.38</td>
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<td>Body mass index, kilograms/meters(^2)</td>
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<tr>
<td>Time since surgery, months</td>
<td>7.33 ± 2.05</td>
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</tbody>
</table>

Nominal data are displayed as number (%), interval and ratio data are displayed as mean ± standard deviation.
Additionally, the non-significant, weak to moderate correlations may indicate the SLVH and horizontal jump tests assess different performance constructs. It is important to recall the context of these findings as the data in the current study is from patients during middle to later stages of rehabilitation after ACLR, all of whom had the goal of returning to sport.

In this cohort, the asymmetry of LSI on the SLVH was approximately 10% or more than each of the horizontal hop tests. This large asymmetry is relevant to clinicians as the lower LSI on the SLVH compared to the horizontal hop tests may indicate that the SLVH test identifies performance deficits that commonly used horizontal hop tests may not. The results are in agreement with those of Taylor et al. who found that participants after ACLR exhibited significant side-to-side differences during the SLVH with the involved limb hopping to a lower height. Biomechanical studies have found that participants after ACLR demonstrate a reduced angular impulse at the knee and greater inter-joint coordination asymmetry on the SLVH test. King et al. demonstrated similar findings with large effect size differences in internal knee valgus moment and posterior center of mass distance on a single leg drop jump task at nine months post ACLR. Performance deficits on the SLVH may correlate to these biomechanical deficits and may be clinically relevant for healthcare providers who use these tests in determining readiness for athletic activities or to guide rehabilitation.

Previous authors have shown that the SLVH is positively correlated with patient-reported IKDC scores, Tegner activity scale, ACL-RSI scale, isokinetic extensor muscle strength, carioca, and shuttle run tests. The relationship between SLVH and quadriceps strength may be of particular importance as better quadriceps function after ACLR is associated with improved patient reported outcome measures, gait quality, and return to sport rates, and reduced risk of re-injury. These additional measures were not directly measured in this study, however the previously documented findings serve to justify the use of the simple clinical test.

The weak correlations between the SLVH test and the horizontal hop tests indicate that the SLVH test likely provides a different assessment of the functional status of the knee. In this cohort, 77.78% of patients demonstrated LSI ≥ 90% on all horizontal hop tests at 7.33 ± 2.05 months after surgery. The pass rate exceeds the pass rate of 52.5% at 12 months after surgery reported by Logerstedt et al. from the Delaware-Oslo Cohort. This suggests the current cohort was made up of high performers, however only 33.33% of patients demonstrated LSI ≥ 90% on the SLVH. This is clinically relevant as the horizontal hop testing data would suggest this group was made up of high performers, while the SLVH detected persistent knee function deficits.

Traditional horizontal hop testing alone after ACLR may not capture bilateral or absolute deficits. Similarly, normal hopping function is difficult to define as even healthy athletes may not be symmetrical. Patterson et
al. identified performance deterioration of the uninvolved limb between one and five years after ACLR suggesting inter-limb comparisons may be flawed as the uninvolved limb may not be functioning optimally after surgery due to de-conditioning.\textsuperscript{48} Acknowledging the importance of absolute values, Wellsandt et al. proposed testing the contralateral limb pre-operatively to establish a baseline value before surgery when using LSI as part of RTS decision making.\textsuperscript{30} It is important to acknowledge the limitations of hop testing. Even if LSI calculated on horizontal hopping performance is to be used as part of the RTS decision, the strategy by which athletes hop must be considered. In their systematic review with meta-analysis of 624 patients after ACLR, Kotsifaki et al. found that athletes may demonstrate adequate distance on the SHD by adopting hip, knee, and ankle strategies suggesting horizontal hop tests alone may be misleading.\textsuperscript{34}

Recent studies observing the validity of RTS testing and outcomes have shown no significant relationship between passing hop tests and re-injury.\textsuperscript{19,31,32} Similarly, passing RTS batteries may not guarantee successful return to sport or be associated with optimal knee function.\textsuperscript{51} However, other authors have suggested that RTS testing is associated with reduced re-injury risk.\textsuperscript{10–12} Clinical testing for RTS remains controversial however a primary benefit testing is that it provides the ability to longitudinally track progress over time. Clinical tests such as SLVH and horizontal hop testing are cost-effective, simple to perform, and empower both the patient and healthcare team to objectively assess recovery and guide functional progression through the rehabilitation process. Additionally, more comprehensive testing procedures that include outcome measures such as diverse hopping tasks, strength, power, movement quality, and psychological status can provide valuable information and more broadly assess recovery and may add value.\textsuperscript{26,27,49,50} A holistic approach to RTS testing can help clinicians carefully assess and guide each patient through return to sport rather than be used as a simple pass or fail concept.\textsuperscript{37,51–53}

While the data from this study adds to the discussion regarding hop testing, there are several limitations. This study was a retrospective cohort analysis, which could introduce selection bias. Careful consideration was given to the inclusion and exclusion criterion to minimize this risk. Similarly, in this cohort, only the included hop tests were uniformly performed and reported on. Other assessments of function, strength, power, and patient-reported outcome measures were used, but in an evolving manner that reflects clinical practice and were not identical among subjects or appropriate to report. Relationships between these additional measures and SLVH are purely speculative. All subjects were NCAA Division 1 collegiate athletes, played a variety of sports, and were operated on and provided rehabilitation by providers from a single institution; the results therefore cannot be generalized to all patients. Furthermore, the horizontal hop test pass rates at 7.33 ± 2.05 months after surgery exceeded previously reported pass rate at 12 months and likely do not reflect the performance of all patients after ACLR. Tests with high inter-rater reliability were used to minimize error.\textsuperscript{30} For example, jump mats are accurate, reliable, and cost efficient when compared to a 3-dimensional motion capture system and is correlated with force plate assessment of jump height.\textsuperscript{38,54–56} The T6H test, which was timed with a standard timer may

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**Figure 3.** LSI for the SLVH compared to the four horizontal hop tests, with SLVH (y-axis) compared to the four horizontal hop tests (A-D, x-axis).

LSI: Limb Symmetry Index, SHD: Single hop for distance, THD: Triple hop for distance, CHD: Crossover hop for distance, T6H: Timed 6-meter hop, SLVH: Single leg vertical hop for height
result in faster times compared to automatic timers and should be interpreted with caution. Additionally, it is important to consider other variables that could affect jump height such as jump type, strategy, and instructions. Therefore, instructions were to perform countermovement, single leg vertical hop as high as possible and hold the landing on the testing leg for two seconds and not excessively flex the hips while in the air to prevent artificially increasing flight time.

Future studies should assess the relationship between SLVH and other assessments and include longer tracking of outcomes related to autograft failures, contralateral ACL tears, and return to performance.

CONCLUSION

The results of this study indicate that SLVH elicits different LSI values after ACLR than horizontal hop tests. In this cohort, the majority of patients who performed well on horizontal hop tests did not perform as well on the SLVH. Clinicians should strive to use the most valid and appropriate tests to assess outcomes after ACLR and should consider using SLVH as horizontal hop testing may not capture all deficits in performance.

CONFLICTS OF INTEREST

The authors have no financial disclosures to report.

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REFERENCES


The Relationship between Landing Error Scoring System Performance and Injury in Female Collegiate Athletes

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Keywords: musculoskeletal injury, landing error scoring system, collegiate athletes, markerless motion-capture

Background
The Landing Error Scoring System (LESS) is a standardized tool used to identify aberrant biomechanical movement patterns during a jump-landing task. Prior authors have examined the value of the LESS in identifying ACL injury risk in athletic populations. Yet, no study has evaluated the association between LESS performance and incidence of any type of lower extremity injury in female collegiate athletes across multiple sports.

Purpose
The purpose of this study was to examine the association between LESS performance as measured with a markerless motion-capture system and lower extremity injury in female collegiate athletes.

Study Design
Prospective cohort study.

Methods
One hundred and ten DI female collegiate athletes (basketball, n=12; field hockey, n=17; gymnastics, n=14; lacrosse, n=27; softball, n=23; volleyball, n=17) completed a jump-landing test prior to the start of their sport seasons. The LESS was automatically scored using a Microsoft Kinect sensor and Athletic Movement Assessment software (PhysiMax®). Participants were tracked throughout one competitive season for incidence of time-loss lower extremity injury. A Receiver Operating Characteristic curve determined the optimal cutpoint for the total LESS score for predicting injury. Pearson's Chi squared statistics examined the association between injury and LESS total scores >5. The Fisher exact test evaluated group differences for the frequency of receiving an error on individual LESS test items.

Results
Female collegiate athletes with LESS scores >5 were not more likely to be injured than those with scores ≤5 (χ²=2.53, p=0.111). The relative risk of injury to this group was 1.78 (95% CI=0.86, 3.68) while the odds ratio was 2.10 (95% CI=0.83, 5.27). The uninjured group was more likely to receive an error on lateral trunk flexion at initial contact than the injured group (p=0.023).

Conclusion
The LESS total score was not associated with an increased odds of lower extremity injury.
in this cohort of female collegiate athletes. Future studies to examine the association between individual LESS item scores and injury are warranted.

Level of Evidence
1b.

INTRODUCTION

Lower extremity musculoskeletal injuries (MSK-Is) occur frequently in collegiate athletics, particularly within sports that require constant acceleration, deceleration, and quick directional changes across the court or field of play.\(^1\) Epidemiological reports have shown these injuries to be especially common in female athletes, with many occurring from non-contact mechanisms.\(^2-6\) Specifically, injuries to the lower extremity account for 69.5 and 72.7% of all practice-related injuries in field hockey\(^4\) and lacrosse,\(^5\) respectively; they represent 45.3 and 61.1% of all game-related injuries within these sports. Regarding sex-comparable sports (e.g., soccer, basketball, and lacrosse), females have a higher frequency of severe injuries, or those restricting participation for > 21 days, to the knee and lower leg, ankle, or foot,\(^7\) as well injuries specific to the anterior cruciate ligament (ACL).\(^8\) These injury rates have led researchers to develop clinical assessment tools to identify potentially modifiable risk factors for injury, so that targeted injury prevention strategies can be implemented in effort to reduce injury risk.

The Landing Error Scoring System (LESS) is a reliable\(^9,10\) and valid\(^10\) standardized scoring rubric used to identify aberrant trunk and lower extremity movement patterns during performance of a jump-landing task. Although originally developed to identify individuals at elevated risk for non-contact ACL injuries,\(^10,11\) more recent work has investigated the association between LESS and risk of all injuries.\(^12,15\) To date, conflicting findings have been reported regarding the relationship between LESS scores and risk of injury,\(^12,15\) including those to the ACL.\(^11,14\) However, only Smith et al.\(^14\) included collegiate athletes as participants though the injury definition was specific to non-contact ACL injury only. Findings revealed that the LESS total score was not associated with an increased risk of non-contact ACL injury. Notably, the LESS evaluates numerous specific lower extremity and trunk biomechanical movement patterns (individual LESS items) in addition to providing a composite score. The identification of individual LESS item errors that are related to injury may be useful in overall injury prevention efforts as specific faulty movement patterns can be targeted with appropriate intervention programs. Yet, only one study to date has compared the frequency of errors on individual LESS items by injury status.\(^11\) Further, it is important to consider that LESS performance may be associated with any lower extremity injury and not just specific to the ACL. The one published study evaluating LESS scores and the incidence of any lower extremity injury in an athletic population found no differences in LESS total scores between the injured and uninjured groups.\(^15\) However, the study was limited by a small sample size and no analysis of an association between total LESS scores and injury was presented. Overall, there are limited data on LESS performance and injury incidence in collegiate athletes.\(^14,15\) One potential limitation of the LESS is that it requires trained evaluators to score video-recorded jump-landing trials following the completion of testing.\(^10\) Therefore, this time-intensive process may limit its application for examining large groups of athletes, which is typical in collegiate athletic settings. The use of marker-less motion capture technology has been presented as an alternative time-expeditious and objective method for scoring the LESS as scores are generated automatically following each trial. Notably, prior studies have shown this technology to have similar reliability to expert raters using the LESS to score jump-landing task performance.\(^16,17\)

To date, no study has evaluated the association between LESS performance (total score and individual items) and incidence of any lower extremity injury in female collegiate athletes across multiple sports. Therefore, the purpose of this study was to examine the association between LESS performance as measured with a markerless motion-capture system and lower extremity injury in female collegiate athletes. It was hypothesized that higher total LESS scores would be associated with an increased odds of lower extremity injury in female collegiate athletes.

METHODS

STUDY DESIGN

This study utilized a prospective cohort design. Between August 2017 and January 2018, female collegiate student-athletes from one NCAA Division I university completed a standardized jump-landing test prior to the start of their respective sport’s competitive season. Participants were subsequently followed throughout their competitive seasons (fall, winter, or spring sports) for incidence of lower extremity injuries.

PARTICIPANTS

In total, 116 student-athletes completed LESS testing prior to the start of their competitive seasons. Of those, data from five participants were excluded due to participants departure from their teams before the completion of the competitive season and one for data collection error (failure of system to record all three trial reps). This resulted in a final sample of 110 participants (age = 19.6 ± 1.5 years, age range 18 – 24 years; height = 168.2 ± 8.8 cm; mass = 67.6 ± 10.2 kg) from the following sports: basketball (n = 12), field hockey (n = 17), gymnastics (n = 14), lacrosse (n = 27), softball (n = 25), and volleyball (n = 17). The inclusion criterion was medical clearance to perform the jump-landing assessment. Participants were excluded if they had any current injury and/or musculoskeletal pain that limited their ability to complete the assessment as determined by the university sports medicine staff.\(^18\) All participants were educated on the study design and procedures and provided written informed consent before testing. This study was approved by...
the institutional review board at Towson University.

PROCEDURES

All testing was conducted within the university's performance laboratory prior to the start of each sport's competitive season. Participants were shod and wore self-selected athletic attire (e.g., shorts or spandex, t-shirts) during performance of the jump-landing assessment. Following confirmation of study inclusion criteria, participant characteristics, including age, height, and weight were recorded. The jump-landing test was performed using a standardized protocol adapted from previous studies. The participants began the assessment standing on a 30-cm-high box and jumped to a designated mark located 90 cm in front of the box. Participants were instructed to (1) jump forward off the box and not vertical, and to ensure that the both limbs left the box simultaneously; (2) land on both feet just past the designated mark; and (3) perform a maximal vertical jump immediately upon landing. Prior to testing, participants were provided a visual demonstration and asked if they understood the directions; all subsequent questions were answered by a study investigator. Participants completed a minimum of one practice trial followed by three successful trials of the jump-landing test. Participants were permitted to rest as necessary between trials. A trial was excluded and repeated if the participant failed to complete the jump as instructed or did not complete the movement in a fluid motion, or if the motion capture system was unable to score the trial based on capturing error. Additional trials were needed for 16.4% (18 of 110) of participants based on these criteria. Roughly half (44.4%; 8 of 18) of these participants required additional trials due to improper jump performance; 55.6% (10 of 18) were due to machine error. The majority (88.9%; 16 of 18) of participants required one additional trial while two (11.1%) completed two extra jumps.

A Kinect v2 sensor was used to capture all kinematic variables. The depth camera (Kinect, version 2; Microsoft Corp, Redmond, WA, USA) was placed 3.4m in front of the box at a height of 0.84m from the floor on a commercially available tripod, and was controlled by a standard laptop computer. Athlete Movement Assessment software (PhysiMax Technologies Ltd, Herzliya, Israel) was used to examine the depth-camera data. As previously described, this marker-less motion capture system ('PhysiMax system') automatically captures and processes depth camera data using proprietary kinematic machine-learning algorithms. The system tracks and refines virtual markers on the participant's body to measure joint angles during performance of various movement assessments. For the LESS, the system captures and uses kinematic data to assess each test item and automatically computes a total score. Findings from a recent validation study revealed overall moderate agreement between the 'PhysiMax system' and a traditional 3-dimensional motion capture system for lower extremity and trunk angles during performance of a jump landing task (Intraclass correlation coefficient ICC average = 0.58). Specifically, better agreement was reported for sagittal ICC average = 0.84) than frontal plane (ICC average = 0.35) kinematics. Further, the 'PhysiMax system' has been validated against expert LESS raters (average $\kappa = 0.48 \pm 0.40); prevalence and bias-adjusted average $\kappa = 0.71 \pm 0.27$; percentage agreement $= 0.85 \pm 0.14$) using the LESS to score performance on a standardized jump landing task.

THE LESS SCORE

The LESS is a standardized screening tool used to identify aberrant movement patterns during performance of a jump-landing test. The LESS has been shown to have good intrarater and excellent interrater reliability. Further, the ability of the LESS to assess jump-landing movement patterns has been validated against traditional 3-dimensional motion capture systems. In its original form, the LESS scoring rubric is comprised of 17 items that evaluate lower extremity and trunk kinematics at initial contact with the ground and the time between initial ground contact and maximal knee flexion. More recently, examiners have expanded the scoring rubric to include five additional items, increasing the total possible items scored to 22. A higher LESS score equates to a greater number of landing errors or presence of aberrant moving patterns during performance of the jump landing test. In the present study, a modified scoring rubric adapted from the 22-item LESS scoring system was used to ensure that only items automatically scored by the 'PhysiMax system' were included. Ultimately, this led to the omission of two items from the total score calculation. First, the marker-less motion capture system did not provide scores for the item assessing knee "wobble" upon landing. Second, the system is unable to provide a score for the "overall impression" item as this is a subjective assessment of the movement in its entirety. However, the PhysiMax system does provide the examiner the option to manually input a score for this item at the conclusion of each trial. Given the subjective nature of this 2-point scoring item and the potential for evaluator bias, this item was omitted from the total score calculation. Therefore, the maximum total LESS score in the present study was 21.

INJURY DATA

Throughout each team's competitive season, university sports medicine staff members recorded injury data for all participants into an electronic medical record database (Athletic Training Systems; Keffer Development Services, Grove City, PA, USA). Injury characteristics included body part (e.g., hip, knee, ankle), injury type (e.g., sprain, strain, stress fracture), activity at time of injury (practice, game, conditioning session, or insidious onset), mechanism (contact or non-contact), and days of time loss. An "injury" was defined as any injury to the lower extremity that occurred during or as result from participation in an organized practice, game, or conditioning session, required medical intervention by an athletic trainer, and resulted in complete restriction from one or more practices or games. Participants were included in the injury group following an initial injury incidence; multiple injuries to the same participant were not included. All injury data were abstracted from the electronic medical record database by one of the authors.
Table 1. Descriptive Statistics for Landing Error Scoring System Total Scores by Sport

<table>
<thead>
<tr>
<th>Sport</th>
<th>n</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basketball</td>
<td>12</td>
<td>6.00 ± 2.13</td>
<td>3 – 10</td>
</tr>
<tr>
<td>Field Hockey</td>
<td>17</td>
<td>5.24 ± 1.75</td>
<td>2 – 8</td>
</tr>
<tr>
<td>Gymnastics</td>
<td>14</td>
<td>5.07 ± 1.69</td>
<td>2 – 8</td>
</tr>
<tr>
<td>Lacrosse</td>
<td>27</td>
<td>5.44 ± 1.65</td>
<td>3 – 9</td>
</tr>
<tr>
<td>Softball</td>
<td>23</td>
<td>6.78 ± 1.95</td>
<td>3 – 11</td>
</tr>
<tr>
<td>Volleyball</td>
<td>17</td>
<td>5.24 ± 1.56</td>
<td>3 – 8</td>
</tr>
</tbody>
</table>

Table 2. Association between LESS performance and lower extremity injury

<table>
<thead>
<tr>
<th>Test Variable</th>
<th>Variable Range</th>
<th>N</th>
<th>Odds Ratio (95% CI)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LESS total score</td>
<td>≤ 5</td>
<td>55</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>&gt; 5</td>
<td>55</td>
<td>2.10 (0.83, 5.27)</td>
<td>0.111</td>
</tr>
</tbody>
</table>

LESS = landing error scoring system

STATISTICAL ANALYSES

The marker-less motion capture system automatically scored all 20 items for each leg. An error was included in the final data set when it was recorded for an individual LESS item on at least two of three trials for either leg. The total score was computed as the sum of errors (0 or 1) across all included items. Descriptive statistics were calculated for demographic and total LESS scores. A Receiver Operating Characteristic (ROC) curve was calculated to determine the optimal cutpoint for the total LESS score for predicting lower extremity injury. Based on the ROC curve analysis, a cut-score of 5.5 was used to dichotomize LESS performance as "good" or "poor" (≤ 5 vs. > 5). Pearson’s Chi squared statistics were used to examine the association between lower extremity injury and LESS total scores > 5. In addition, logistic regression was used to examine the odds of injury with LESS total score as a continuous variable. For both analyses, "injured/uninjured" was the dependent variable. Finally, the Fisher exact test was used to determine differences between the injured and uninjured groups for the frequency of receiving an error on each individual LESS test item. An alpha level of ≤ 0.05 was used to determine statistical significance. Data analyses were performed using Statistical Package for the Social Sciences version 25.0 (SPSS, Inc., Chicago, IL, USA).

RESULTS

Twenty-five participants suffered a lower-extremity injury during their competitive season. The ankle was the most commonly injured body segment (28.0%, n = 7), followed by the lower leg (20%, n = 5), thigh (20%, n = 5), foot (20%, n = 5), and knee (12.0%, n = 3). Sprains (n = 9) and muscle strains (n = 7) comprised 64.0% of all injuries. Non-contact and contact injuries represented 76.0% (n = 19) and 24.0% (n = 6) of all injuries, respectively. Almost half of the injuries occurred during practice (48.0%, n = 12), while the remaining were recorded as occurring during a game (16.0%, n = 4), conditioning session (12.0%, n = 3), or having an insidious onset (24%, n = 6). Seventeen injuries (68.0%) resulted in time loss ≤ 1 week while three (12.0%) led to time loss between eight days and one month; five (25.0%) resulted in time loss of > 1 month.

The mean LESS score for all participants was 5.67 ± 1.85. Table 1 presents the descriptive statistics for total LESS scores by sport.

The ROC curve for the total LESS score was not significant (AUC = 0.56, SE = 0.07, p = 0.396, 95% CI = 0.43, 0.68) (Figure 1). The cut-point score was maximized at 5.5 (sensitivity = 64.0%, specificity = 54.1%), which is what determined the total LESS score of >5 to be used in this study for further analysis. Notably, this cut-point is consistent with prior studies that used either the traditional 17-item or expanded 22-item LESS scoring rubric to examine the relationship between LESS performance and injury.

The association between lower extremity injury and a total LESS score > 5 is presented in Table 2. As shown, female collegiate athletes with total LESS scores > 5 were not more likely to be injured than those with scores ≤ 5 (χ² = 2.53, p = 0.111). The relative risk of injury to this group was 1.78 (95% CI = 0.86, 3.68) while the odds ratio was 2.10 (95% CI = 0.83, 5.27). No significant association was found between total LESS score as a continuous variable and lower extremity injury (OR = 1.12; 95% CI = 0.88, 1.42; p = 0.376).

Table 3 presents the frequency of errors on individual test items between injured and uninjured participants. As shown, the uninjured group was more likely to receive an error on lateral trunk flexion at initial contact than the injured group (FET, p = 0.023).
Table 3. Number of participants displaying errors on LESS scoring items by injury status

<table>
<thead>
<tr>
<th>LESS Item</th>
<th>No Injury (n = 85)</th>
<th>Lower Extremity Injury (n = 25)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee flexion: initial contact</td>
<td>29 (34.1)</td>
<td>8 (32.0)</td>
<td>1.00</td>
</tr>
<tr>
<td>Hip flexion: initial contact</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Trunk flexion: initial contact</td>
<td>8 (9.4)</td>
<td>4 (16.0)</td>
<td>0.464</td>
</tr>
<tr>
<td>Ankle plantar flexion: initial contact</td>
<td>28 (32.9)</td>
<td>6 (24.0)</td>
<td>0.467</td>
</tr>
<tr>
<td>Asymmetrical foot contact</td>
<td>13 (15.3)</td>
<td>7 (28.0)</td>
<td>0.153</td>
</tr>
<tr>
<td>Asymmetrical foot contact: timing</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Asymmetrical foot contact: plantar flexion</td>
<td>13 (15.3)</td>
<td>6 (24.0)</td>
<td>0.368</td>
</tr>
<tr>
<td>Lateral trunk flexion: initial contact</td>
<td>21 (24.7)</td>
<td>1 (4.0)</td>
<td>0.023†</td>
</tr>
<tr>
<td>Medial knee displacement: initial contact</td>
<td>21 (24.7)</td>
<td>11 (44.0)</td>
<td>0.080</td>
</tr>
<tr>
<td>Stance width: wide</td>
<td>1 (1.2)</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>Stance width: narrow</td>
<td>55 (64.7)</td>
<td>16 (64.0)</td>
<td>1.00</td>
</tr>
<tr>
<td>Foot position: internal rotation</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Foot position: external rotation</td>
<td>16 (18.8)</td>
<td>5 (20.0)</td>
<td>1.00</td>
</tr>
<tr>
<td>Knee flexion displacement</td>
<td>4 (4.7)</td>
<td>2 (8.0)</td>
<td>0.617</td>
</tr>
<tr>
<td>Hip flexion displacement</td>
<td>1 (1.2)</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>Trunk flexion displacement</td>
<td>29 (34.1)</td>
<td>9 (36.0)</td>
<td>1.00</td>
</tr>
<tr>
<td>Trunk flexion displacement: excessive</td>
<td>82 (96.5)</td>
<td>24 (96.0)</td>
<td>1.00</td>
</tr>
<tr>
<td>Medial knee displacement: maximum</td>
<td>37 (43.5)</td>
<td>16 (64.0)</td>
<td>0.110</td>
</tr>
<tr>
<td>Asymmetrical weight shift</td>
<td>29 (34.1)</td>
<td>8 (32.0)</td>
<td>1.00</td>
</tr>
<tr>
<td>Joint displacement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average†</td>
<td>84 (98.8)</td>
<td>25 (100.0)</td>
<td>1.00</td>
</tr>
<tr>
<td>Poor§</td>
<td>1 (1.2)</td>
<td>0</td>
<td>1.00</td>
</tr>
</tbody>
</table>

*Number of participants displaying the error on the individual LESS scoring item; †p < 0.05; ‡Score of 1 on joint displacement; §Score of 2 on joint displacement; LESS = landing error scoring system

DISCUSSION

The purpose of this study was to examine the association between LESS performance and lower extremity injury incidence in a cohort of female collegiate athletes across multiple sports. A key finding was that the LESS total score was not associated with an increased odds of lower extremity injury. To date, conflicting findings regarding the association between total LESS scores and future injury risk have been reported,\textsuperscript{11–14} which may be attributed to the methodological heterogeneity across studies. Notably, the present study is the first to examine the association between LESS total scores and incidence of any lower extremity injury in female collegiate athletes with findings suggesting that LESS performance is not related to injury in this population. These results are aligned with recent systematic reviews that have questioned the ability of clinical movement assessments, including the LESS, to identify future MSK-I risk in some athletic and military populations.\textsuperscript{20,23}

Since the LESS evaluates kinematics during the landing phase of a jump from a standardized height, adequate neuromuscular control is required for satisfactory performance, as determined by fewer identified errors. Markedly, ineffective neuromuscular control has been reported as a risk factor for non-contact ACL\textsuperscript{24,25} and other lower extremity injuries,\textsuperscript{26,27} and therefore has been a target of prior injury prevention efforts.\textsuperscript{28–30} To date, two prospective studies have examined the ability of the LESS (17-item scoring

Figure 1. Receiver Operator Characteristics (ROC) Curve examining the ability of the total LESS scores to predict lower extremity injury risk in female collegiate athletes.
rubric) to identify athletes at increased risk for non-contact ACL injury.\textsuperscript{11,14} Padua et al.\textsuperscript{11} reported that elite–youth soccer players with a total LESS score of five or higher were at increased risk for non-contact ACL injuries than those scoring below this cutpoint. Further, the mean LESS score was higher in ACL-injured athletes than the non-injured group (6.24 ± 1.75 vs. 4.43 ± 1.71). In contrast, Smith et al.\textsuperscript{14} reported no significant associations between total LESS scores and risk of non-contact ACL injury in cohorts of high school and collegiate athletes. Given the methodological differences between these two investigations and the present study, such as our use of a modified 20-item scoring rubric and broader injury definition, comparisons across studies are limited. The rationale for including an injury definition that included all lower extremity injuries irrespective of injury mechanism was two-fold and warrants acknowledgement. First, non-contact ACL injuries represent only a small portion of all injuries\textsuperscript{8} and thus including a more comprehensive injury definition allowed for the examination of the relationship between LESS scores and injury across the entire lower extremity. Second, the LESS, like most clinical screening tools, allows for the evaluation of specific lower extremity and trunk biomechanical movement patterns (individual LESS items), that may be related to numerous lower extremity pathologies.\textsuperscript{31} Nonetheless, it is worth noting that of the 25 injured participants in the present study, one sustained a non-contact ACL injury and was recorded of having a total LESS score of three. Regarding injury mechanism, it is also notable that of the 25 documented injuries, 19 (76.0%) were recorded as occurring from non-contact mechanisms. Consistent with the findings presented in Table 2, a secondary data analysis revealed no significant association between total LESS score ≥ 5 and odds of non-contact lower extremity injury (OR = 1.91; 95%CI = 0.69, 5.30).

The present study is the first to examine the association between LESS performance and incidence of any lower extremity injury in female collegiate athletes across multiple sports. In a previous study, no significant difference in total LESS scores (17-item rubric) was found between male and female collegiate soccer players who sustained a lower extremity injury. In the present study, such as our use of a modified 20-item scoring rubric and broader injury definition, comparisons across studies are limited. The rationale for including an injury definition that included all lower extremity injuries irrespective of mechanism in a population of female collegiate athletes across multiple sports, suggest that the total LESS score may not be associated with an increased odds of injury. As previously stated, it is reasonable to propose that the methodological heterogeneity across studies may be the reason for the conflicting findings supporting LESS’s predictive value for injury. In addition to the aforementioned variations in scoring rubrics and injury definitions, population characteristics, such as proportion of male and female participants, sport and level of play (i.e. youth, high school, and college), have differed across studies to date.\textsuperscript{11,14,15} Notably, high school athletes have been found to have higher LESS scores than college athletes,\textsuperscript{14} suggesting the influence of age on test performance. Likewise, a recent review that included a meta-analysis of twelve studies revealed that females had higher LESS scores than males, though the mean difference (0.6) was not clinically meaningful.\textsuperscript{34} In sum, these findings suggest that LESS scores, as well as their association with injury incidence, may be influenced by the sex, sport, and playing level of the athletic population. Therefore, additional efforts to examine the association between LESS performance and lower extremity injury in male and female athletes across various levels of play are warranted.

Although several studies have examined the association between total LESS scores and lower extremity injury in athletic populations, limited data exists on the relationship between performance on individual LESS items and injury. In a previous study, Padua et al.\textsuperscript{11} reported that trunk flexion displacement and overall joint displacement were the most predictive items for identifying non-contact ACL injury risk in youth soccer athletes. In the present investigation, only lateral trunk flexion at initial contact was related to future lower extremity injury as the uninjured group was unexpectedly more likely to demonstrate this fault than those who remained uninjured. Worth noting is that these results are based on a small number of total injuries (n = 25) and fewer or no errors were identified. Despite this limitation, the finding that errors occurred infrequently for items such as hip flexion at initial contact, foot position: internal rotation, and hip flexion displacement, is similar to results presented by Padua et al.\textsuperscript{11} In another study, investigators examined sex differences in the most commonly occurring errors in male and female military cadets. Findings revealed that females were more likely to land with decreased hip and knee flexion as well as increased medial knee displacement at initial contact than their male counterparts yet no relationship to injury incidence was examined.\textsuperscript{35} Notably, similar results regarding the frequency of increased medial knee displacement were found in the present study as 30% (35 of 110) of all participants presented with this error. Further, injured participants were more likely to display this error than the uninjured group, though results were not statistically significant (p = 0.080). Since the LESS scoring rubric identifies errors for multiple trunk and lower extremity movements, it is possible that individual item scores may have clinical application for injury prevention purposes. Therefore, future efforts to examine the association between individual LESS item scores and injury across varying athletic populations are warranted.
Recent authors have examined the relationship between LESS total scores and incidence of all MSK-Is in military populations. In a study of 132 male entry-level military recruits undergoing 16-weeks of fitness training, authors reported that recruits with LESS scores (17-item rubric) $> 5$ had a relative risk of 2.2 (95% CI = 1.0 – 1.7) for any MSK-I compared to those with scores $\leq 5$. In more recent work, de la Motte et al. reported that total LESS scores (22-item rubric) were predictive of any MSK-I in a large cohort of 1,714 male and female military trainees throughout their initial 180 days of service. However, results revealed that military trainees categorized as having good LESS performance, as determined by the median score of 5.7, were more likely to be injured than those with higher LESS scores (poor performance). The authors recommended using caution when interpreting the clinical application of these findings since LESS scoring reliability may be influenced by scoring error and rater expertise. Notably, the recent development of marker-less motion capture technology, as used in the present study, may be a suitable method for limiting the potential influence of rater error, particularly when large samples of athletic or military cohorts are examined.

A novel aspect of the present study is that LESS measures were automatically provided by the 'PhysiMax' system, whereas prior studies examining the association between LESS performance and injury utilized the traditional video recording and scoring method. In a prior study, Mauntel et al. reported the 'PhysiMax system' to have similar reliability to expert LESS raters (average $\kappa = 0.48 \pm 0.40$; prevalence $\kappa = 0.71 \pm 0.27$; percentage agreement $= 0.85 \pm 0.14$), with good to perfect agreement noted for the majority of test items (71.4%; 15 of 21). The authors noted the clinical relevance of these findings since use of expert raters to score the LESS is common in both research and clinical practice. Further, this system was used in a recent study examining stress fracture risk factors, including biomechanical movement patterns measured by the LESS, and bone metabolism in a military population.

Despite the present study’s finding that LESS performance was not related to future lower extremity injury in female collegiate athletes, this marker-less motion capture system was successful in providing an objective and immediate evaluation of jump landing performance in a large cohort of athletes. Therefore, the use of this technology may have clinical application beyond injury risk prediction, such as identifying the most frequently occurring faulty movement patterns across a group of athletes to assist with developing team-specific corrective exercise programs as well as to help monitor the rehabilitation progress of an individual athlete following lower extremity injury. Worth noting is that the results from LESS testing (total scores and errors on individual test items) were not utilized by members of the sports medicine team for the development of individual or team-specific injury prevention exercise programming during the follow-up period in the present study. Athletic trainers and strength and conditioning coaches for each sport had the ability to develop individual team programming at their discretion; however, these decisions were made independently by the sports medicine team and results were not monitored as an outcome of this study.

The average LESS score for participants playing softball (6.78 ± 1.95) was higher than those from other sports. Further, the sports with the lowest average LESS scores in order were gymnastics, field hockey, and volleyball, which all require a higher frequency of cutting and jumping movements. Notably, findings from a recent meta-analysis revealed that neuromuscular training programs of at least six weeks in duration that included plyometric exercises and feedback on jump landing technique resulted in meaningfully improved LESS scores. Although the LESS scores captured in the current investigation were not utilized in guiding injury prevention programming for participants during the follow-up period nor was the performance of other injury prevention efforts monitored, it is reasonable to suggest that the neuromuscular demands associated with these sports may have influenced the lower scores achieved by their participants. Future studies may want to consider examining between sport differences in LESS performance across a multitude of different team and individual sports of varying physical and neuromuscular demands.

This study has several limitations. First, the study sample included female athletes from five different sports, each comprised of different sample sizes. In addition, basketball, field hockey, and lacrosse are categorized as contact sports whereas volleyball and gymnastics are classified as non-contact sports. Second, results revealed a relatively small number of participants ($n = 25$) who sustained a lower extremity injury during the follow-up period (one competitive season). Consequently, it was deemed inappropriate to examine the association between LESS performance and injury to specific segments (e.g., ankle, knee) or structures (ACL), which has been the focus of some prior studies. However, it is important to note that the injury definition used in the present study was selected because the LESS allows for the evaluation of numerous lower extremity and trunk movement patterns, which may be related to various lower extremity pathologies. Third, the 22-item LESS scoring rubric was modified so that only items automatically scored by the 'PhysiMax System' were included in the total score calculation. Although this limited comparisons between total LESS scores from the present investigation and those from previous studies, this omission eliminated any potential for evaluator error or scoring bias. Fourth, roughly 10% of participants were required to complete additional trials based on the system’s inability to score jumps due to capturing error. Despite this requirement, it is notable that this error is immediately visible to the evaluator so that additional trials can be performed during the testing period. Further, this additional time requirement is minimal compared to the potential time spent manually reviewing and scoring jumps using the traditional LESS testing method. Finally, potential confounding variables, such as prior history of lower extremity injury, were not assessed.

CONCLUSION

The present findings suggest that LESS performance is not associated with future lower extremity injury in a cohort of female collegiate athletes across multiple sports. Notably, these results are aligned with some prior studies that also reported the total LESS score was unable to prospecti-
tively identify risk of injury in athletic or military populations.\textsuperscript{12,14} Therefore, practitioners may want to exhibit caution when using the LESS total score as a stand-alone injury prediction tool. However, future studies to examine the association between individual LESS item faults and injury are warranted. Despite these results, the use of a markerless motion capture system to automatically and objectively score a commonly used clinical assessment may have practical application for sports medicine and strength and conditioning professionals interested in evaluating movement patterns in individual or large groups of athletes. Specifically, use of this technology may be an effective time-expedient strategy for assessing movement patterns in an entire team or during pre-participation examinations. Since both total and individual test item scores are automatically provided, results are readily available to assist in the development of corrective exercise programs targeted at improving the most frequently identified movement impairments.

\textbf{ACKNOWLEDGMENTS}

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Original Research

Dynamic Balance is Similar Between Lower Extremities in Elite Fencers

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Background

Few studies have quantified dynamic balance in fencers despite previous suggestions that balance training may be beneficial for these athletes. Generally, asymmetry in dynamic balance performance between the left and right legs can be an indicator of lower extremity injury risk and used to monitor rehabilitation progress. Fencing is recognized as an asymmetric sport, therefore, differences in dynamic balance may exist among uninjured athletes.

Hypothesis/Purpose

The primary objective of this investigation was to evaluate whether asymmetry of dynamic balance is present in uninjured national-level fencers. It was hypothesized that elite uninjured fencers would demonstrate superior dynamic balance on the lead-leg of their fencing stance. A secondary objective was to compare dynamic balance performance of elite fencers to previously published data from high-level athletes participating in other sports.

Study Design

Descriptive Laboratory Study

Methods

Fourteen uninjured elite competitive fencers were recruited. Subjects self-reported the lead leg of their fencing stance. Each participant performed the Y-Balance test (YBT), which represented a measurement of dynamic balance control, on both legs. Reach distances were recorded directly from a commercially available YBT apparatus. Four reach distances were recorded: anterior, posteromedial, posterolateral, and a composite measure was calculated. Distances were leg length-normalized and expressed as a percentage. Sample averages and standard deviations were derived for the four YBT measurements.

Results

There were no significant differences in reaching distance between the lead and trail legs in any of the four YBT measures (p ≥ 0.65). Fencers appeared to demonstrate larger normalized reach distances in the posterolateral and posteromedial directions than other
athletes.

Conclusions

The results of this study indicate that dynamic balance is not significantly different between the lead and trail legs in elite fencers, despite the asymmetrical nature of their sport. The apparent symmetry of dynamic balance control in uninjured fencers means that the YBT could be used in this population for monitoring progress during training and rehabilitation.

Level of Evidence

2b

INTRODUCTION

Balance, and in particular dynamic balance, is recognized as a fundamental component of athletic performance. Dynamic balance is often operationally defined in athletic contexts by lower extremity reach distances on the Star Excursion Balance Test (SEBT) or the Y-Balance Test (YBT). These tests measure a person’s ability to actively control volitional movement during unipedal stance. Differences in performance between the left and right legs for a given reaching direction, hereafter referred to as asymmetries, can also be used as indicators of lower extremity injury risk and to monitor progress during rehabilitation from an injury.

Previous authors have demonstrated that balance training and assessment may be beneficial for fencing performance, however, there has been limited research on balance performance in fencers. Furthermore, the presence of dynamic balance asymmetry (or lack thereof) in elite uninjured fencers, possibly related to sporting asymmetry, is unknown. A quantitative analysis of dynamic balance performance in elite competitive fencers, and comparison with data reported from elite athletes participating in other sports, is necessary before addressing recommendations related to training, rehabilitation monitoring, and lower extremity injury risk.

As previously mentioned, the literature on balance performance in fencers is limited. Herpin and colleagues investigated the influence of training on weighting of sensory inputs for balance control by comparing expert fencers to expert pistol shooters. Fencers were found to have an enhanced ability to integrate vestibular and proprioceptive information to control static balance than the pistol shooters. Another study used measures from static balance assessments to evaluate the effectiveness of a training program that addressed muscle imbalances in fencers. A possible limitation of these two studies was that the balance task did not require the participant to demonstrate dynamic balance control during volitional movements, which is required during fencing.

More recent studies have evaluated dynamic balance control in fencers with the aims of identifying possible asymmetries and changes following a proprioceptive training program. In the authors’ opinion, the existing literature on balance assessment and training in fencers, implies that symmetry appears to be desirable. The extent to which the bilaterally asymmetric nature of fencing, attributable to the split stance adopted during competition, contributes to asymmetry during dynamic balance assessment is likely an important consideration. Evidence of morphological and functional sporting differences between the lead and trail legs have been reported in fencers. Morphologically, greater cross-sectional area of the thigh of the fencer’s lead leg has been reported. Electromyographic studies have demonstrated that the trail hip, knee and ankle extensor muscles are concentrically predominant during the propulsive phase of lunging movements, whereas the lead leg extensors are eccentrically predominant during the landing phase of lunging movements. Nystrom and colleagues reported greater isometric and isokinetic strength for the fencer’s lead leg; however, more recent evidence using a larger sample size of national-level fencers did not identify a significant difference between the lead and trail legs for isokinetic knee extension strength.

Evaluations of dynamic balance performance in fencers also appear to be divided regarding the presence of asymmetries between the lead and trail legs. Consistent with the approach used for athletes in other sports, recent studies evaluating dynamic balance in fencers have used the SEBT. The SEBT requires the athlete to perform a series of single leg squats while reaching in 8 different directions (anterior, anterolateral, lateral, posterolateral, posterior, posteromedial, medial, anteromedial) with their contralateral lower extremity. The reach distance of the contralateral lower extremity is used as a measure of dynamic balance proficiency. Guan and colleagues noted greater reaching distance in the posterolateral direction for the lead-leg of child fencers. Conversely, baseline measures of dynamic balance in club-level fencers between the ages of 14 and 35 did not reveal any differences between the lead and trail legs. To date there has not been an evaluation of dynamic balance performance in a group of elite fencers.

The primary objective of this investigation was to evaluate whether asymmetry of dynamic balance is present in uninjured national-level fencers. Given the inherent sporting asymmetry of fencing, it was hypothesized that elite fencers would demonstrate superior dynamic balance on the lead-leg of their fencing stance. A second objective was to compare dynamic balance proficiency in elite fencers to that of other high-level athletes found in other studies. This may have implications for fencing-specific considerations when designing balance training programs or adapting those that were previously developed for athletes of other sports. For example, the proprioceptive training program implemented by de Vasconcelos and colleagues was adapted from a program originally developed for athletes having sustained ankle sprains.
MATERIALS AND METHODS

PARTICIPANTS

A convenience sample of healthy adults aged 18-32 years was recruited for this study from a pool of elite fencing athletes in Canada. To be included in this study, participants were Canadian fencers, regardless of sex or weapon (sabre, foil, épée), who were competing and had been nationally ranked within the top-16 at any time between the 2016-2019 competition seasons. These inclusion criteria were set to justify an appropriate level of prior training and proficiency. All participants were at least 18 years of age on the date of data collection. Participants were excluded if they were experiencing, or had a history of, musculoskeletal injury to their lower extremities, or pelvis during the three months prior to data collection. This study was approved by the Canadian Memorial Chiropractic College's Research Ethics Board (REB #1810B04). All participants provided written informed consent.

EXPERIMENTAL PROTOCOL

Once consent was received, participants’ demographic and injury history were collected to confirm eligibility. Demographics included sex, height, mass and competitive fencing stance to identify the lead and trail legs.

Athletic attire (shorts and t-shirt) was worn by participants during the data collection session. First, the participant was asked to lie supine on a treatment table. The length of each lower limb was measured as the distance from the anterior superior iliac spine to the medial malleolus of the ankle using a tape measure.22

Participants then observed a video that provided a set of standardized instructions and demonstration for how to perform the YBT.23 The YBT is based on a subset of reach directions (anterior, posterolateral and posteromedial) that are part of the SEBT and has excellent intra-rater reliability (ICC $= 0.85 - 0.89$).3 A YBT trial was defined as a single exertion in one of the three directions. Similarly, a YBT repetition was defined as a complete set of measurements in all three directions for a given lower extremity. All YBT trials were performed with the participant standing unshod on a commercially available apparatus (Y-Balance Test Kit). A research assistant used markings on the YBT apparatus to determine the reach distance to the nearest half-centimeter upon completion of each trial, and manually recorded each measurement on a data collection sheet. The same research assistant was used for all data collections.

First, participants completed six repetitions of the YBT on both their lead and trail legs as practice to mitigate a potential learning effect.24 After completing the six practice repetitions per leg (12 total repetitions), participants completed a total of three experimental repetitions of the YBT standing on both their lead and trail legs. Thus, participants completed a total of nine repetitions of the YBT on each of their lead and trail legs for a total 54 trials (6 practice + 3 experimental) * 2 legs * 3 directions). The order of the starting stance leg (lead or trail) was randomly determined for each participant. Each repetition of the YBT was performed in the order of anterior, posteromedial and posterolateral. Participants were given a minimum of 15-seconds rest between exertions with additional rest time provided upon request. To further mitigate against fatigue, execution of the YBT was performed on alternating legs after each repetition.

DATA HANDLING AND REDUCTION

Written measurements of reach distance from each YBT trial for each participant were transcribed into an electronic spreadsheet. This was completed using a double data entry method. Transcription was independently completed by a research assistant and an investigator who then met to resolve discrepant entries by reviewing the data collection sheet and coming to a consensus.

Table 1

The average reach distance for the anterior, posteromedial and posterolateral trials of each YBT repetition were used to calculate a composite score. Thus, each repetition of the YBT was represented by four measurements. An average across the three experimental YBT repetitions for each of the four measurements was determined for the lead-leg of each participant. The same was done for the trail-leg. This resulted in a single value for each of the four reach distances (anterior, posteromedial, posterolateral and composite) for the lead and trail legs. Finally, participant leg lengths were used to normalize the reach distances.3 Normalized reach distances were expressed as a percentage for subsequent statistical analysis.

STATISTICAL ANALYSIS

All statistical analyses were performed using Excel (Microsoft, Redmond, WA, USA). Sample means, standard deviations, and 95% confidence interval limits for the anterior, posteromedial, posterolateral and composite measures were derived as descriptive statistics. To address the primary objective, differences in reach distances along each direction and the composite measure between the lead and trail legs were statistically evaluated using one-tailed paired t-tests. An alpha level of 0.05 was used for all statistical analyses. Male and female YBT data from Division I collegiate athletes competing in different sports (basketball, golf, hockey, soccer, volleyball, football and wrestling) were used to construct 95% confidence interval limits for a qualitative comparison against dynamic balance proficiency of the fencers.25

RESULTS

Data were collected from 14 fencers. Demographics are reported in Table 1.

Table 2

There were no statistically significant differences in normalized reach distances between the dominant and non-dominant lower extremities (Table 2, $p \geq 0.65$).

The confidence interval for the normalized reach distances in the anterior direction for the fencers at least partially overlapped the confidence intervals for collegiate athletes competing in different sports (Figure 1A). The lower limit of the confidence interval for the normalized reach distance in the posterolateral direction for the fencers was greater than the upper limits of the confidence intervals for collegiate athletes competing in different sports (Figure 1B).
Table 1. Demographics of sample population. Values for age, height and mass are the group means with standard deviations reported in parentheses.

<table>
<thead>
<tr>
<th>Participants</th>
<th>n = 14 (8 female)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>25.8 (4.4)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.75 (0.08)</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>70.5 (11.2)</td>
</tr>
<tr>
<td>Lead Leg</td>
<td>13 Right; 1 Left</td>
</tr>
<tr>
<td>Lead Leg Length (m)</td>
<td>0.93 (0.06)</td>
</tr>
<tr>
<td>Trail Leg Length (m)</td>
<td>0.93 (0.06)</td>
</tr>
<tr>
<td>Weapon</td>
<td>Foil:6; Epee:8</td>
</tr>
</tbody>
</table>

Table 2. Normalized YBT reach distances for the lead and trail legs in each direction and the composite score. All values are reported as a percentage of leg length.

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD) (%)</th>
<th>95% CI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>67 (7)</td>
<td>(63,70)</td>
</tr>
<tr>
<td>Trail</td>
<td>66 (8)</td>
<td>(62,70)</td>
</tr>
<tr>
<td>Posterolateral</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>108 (5)</td>
<td>(105,111)</td>
</tr>
<tr>
<td>Trail</td>
<td>108 (7)</td>
<td>(104,111)</td>
</tr>
<tr>
<td>Posteromedial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>112 (4)</td>
<td>(109,114)</td>
</tr>
<tr>
<td>Trail</td>
<td>111 (5)</td>
<td>(109,114)</td>
</tr>
<tr>
<td>Composite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>95 (6)</td>
<td>(92,98)</td>
</tr>
<tr>
<td>Trail</td>
<td>95 (5)</td>
<td>(92,98)</td>
</tr>
</tbody>
</table>

SD = standard deviation; CI = confidence interval.

DISCUSSION

The present study used the YBT to compare dynamic balance performance between the lead and trail legs of healthy elite fencers. A secondary objective sought to compare YBT performance between elite fencers and Division I collegiate athletes competing in different sports. Given the asymmetrical nature of fencing, it was hypothesized that fencers would demonstrate differences in dynamic balance between limbs. However, the results of the present study showed no statistically significant differences in YBT performance between the lead and trail legs. This indicates that dynamic balance between the two limbs in a group of healthy elite fencers are not significantly different, despite the inherent asymmetry of the sport. These data also showed that fencers may display greater reach distances in the posterolateral and posteromedial directions than other athletes. Historically, research evaluating balance in fencers has focused on their control of upright standing posture. This largely ignores the ability of a fencer to control their balance while performing volitional movements. Two recent studies have used the SEBT, from which the YBT is derived, to evaluate dynamic balance performance in child and club-level fencers. Their authors reported conflicting findings regarding the presence of dynamic balance asymmetry in their participants. The current results were similar to those of de Vasconcelos and colleagues in that there was no observed difference in reach distance between the dominant and non-dominant lower extremities. Conversely, Guan and colleagues identified a side-to-side difference in the posterolateral direction, but their statistically significant findings were derived from combined data from fencers and Tae Kwon Do athletes. One possible explanation for the discrepant findings could be due to the chosen study population. Guan and colleagues studied child fencers with limited experience as their study population, whereas the current study and that of de Vasconcelos and colleagues focused on more experienced and likely more proficient fencers. Anecdotally, more experienced, and more proficient fencers will supplement their fencing training with general strength and conditioning training that may counteract their inherent potential sporting asymmetry. The results of the current study suggest that assessing dynamic balance performance in uninjured elite fencers may contribute to developing training regimens or monitoring...
progress during rehabilitation when asymmetries are present. It also indicates that the morphological and functional asymmetries that have been previously documented in the lower extremities of fencers may not manifest as asymmetries in dynamic balance control; however, this statement must be tempered by the fact that the morphology and lower extremity strength of the fencers in this study was not measured.

Balance training has previously been advocated to aid fencers’ performance. Data presented by de Vasconcelos and colleagues demonstrated that overall dynamic balance improved in fencers after a 12-week proprioceptive training program that was adapted from one developed for athletes with ankle sprains. To the authors’ knowledge, this has been the only study to date that has implemented a balance training program for fencers. Thus, an approach to developing sport-specific balance training programs might be to compare dynamic balance performance between fencers and athletes competing in other sports. For example, the elite fencers in the current study generally demonstrated greater normalized reach distances in the posterolateral and posteromedial directions than American collegiate athletes who competed in a variety of sports. This may be related to the similarity of movement patterns between the posterolateral and posteromedial directions in the YBT and the lunge that is commonly used in fencing. The extent to which lunge-specific training affects YBT reach distances in the posterolateral and posteromedial directions is currently unknown. Furthermore, the relationship between dynamic balance performance and fencing proficiency is also unknown, but greater lunge distance has been observed in elite fencers when compared to their novice counterparts.

There were several limitations of the current study. Although data were obtained from male and female fencers, a sex-specific hypothesis was not formulated and subsequently was not addressed in statistical analyses. This was mainly due to constraints imposed on the sample size by inclusion/exclusion criteria and recruitment efforts. Previous work has demonstrated differences in kinematic strategies between males and females that resulted in greater normalized reach distances in females. No information was obtained regarding the current national ranking of the fencers who participated. Instead, the authors confirmed that the participant had achieved a top-16 national ranking in a three-year period prior to data collection. This decision was made to increase the size of the study population in consideration of the prevalence of lower extremity injuries in fencers and our exclusion criteria of an injury to either lower extremity or the pelvis in the three months prior to data collection. Finally, kinematic and kinetic data were not obtained in this study. These data could have provided information regarding local differences (e.g. joint angle) in movement strategy that may have left the global outcome (i.e. reach distance) unchanged.

**CONCLUSION**

Despite the asymmetrical nature of fencing, the results of the current study indicate that the dynamic balance performance of these elite healthy fencers was not statistically significantly different between their lead and trail legs. An *a posteriori* analysis showed that normalized reach distances of this population were likely to have been greater than...
other elite athletes in the posterolateral and posteromedial directions which may be attributed to their training, though further studies are required to confirm these observations. The apparent symmetry of dynamic balance control in non-injured fencers indicates that the YBT may be used in this population during training, rehabilitation, and assessment.

CONFLICT OF INTEREST [COI]
None to declare.

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Dynamic Balance is Similar Between Lower Extremities in Elite Fencers

International Journal of Sports Physical Therapy
Background
Collegiate distance runners often suffer from running overuse injuries (ROI). The Y-Balance Test (YBT) has the potential to predict ROI risk in collegiate runners.

Purpose
To investigate whether a preseason clinical assessment of dynamic balance, through a modified version of the YBT (mYBT), can predict risk of ROIs during one NCAA Division I cross-country (XC) season.

Study Design
Prospective case-control study

Methods
Participants from a Division I XC team were screened for mYBT performance in four directions: anterior (AN), posteromedial (PM), posterolateral (PL), and posterior (PO). ROIs were tracked over the course of the XC season. Receiver operating characteristic (ROC) curve analysis ($\alpha = 0.05$) was utilized to investigate the effectiveness of the mYBT in predicting injury risk.

Results
Nine (5 female, 4 male) of 29 runners developed an ROI during the XC season. Five components of the mYBT were found to predict injuries, including normalized nondominant PO score (AUC = 0.756, p = 0.03; RR = 1.90), AN raw difference and limb asymmetry (AUC = 0.808, p = 0.01), and PM raw difference and limb asymmetry in males (AUC = 0.958, p = 0.02).

Conclusion
Specific components of the mYBT can help predict the risk of developing a running overuse injury over one Division I XC season.

Level of Evidence
Screening, Level 3
INTRODUCTION

Collegiate runners participating in cross-country (XC) often suffer from overuse injuries, such as patellofemoral pain syndrome, Achilles tendinopathy, medial tibial stress syndrome, and stress fractures. They are collectively known as running overuse injuries (ROIs). Hayes et al reported that 53% of NCAA Division I and III runners suffered a new ROI across one XC season. Such a high prevalence of injuries can be detrimental to runners and their teams. Thus, there is a need to better understand underlying risk factors.

Many risk factors are suggested to contribute to ROIs, including age, sex, previous injury history. However, these factors are all nonmodifiable. In contrast, modifiable factors like training load and biomechanical inefficiencies have generated the interest of clinicians and researchers. Biomechanical measurements of muscle strength, flexibility, and balance are routinely used by clinicians to quantify injury risk through a process known as injury screening.

Injury screening theoretically allows clinicians, coaches, and runners to identify and correct biomechanical inefficiencies, thereby reducing the likelihood of sustaining ROIs. The most practical injury screens are inexpensive, time efficient, and valid in predicting injuries. Several measures have been proposed to help predict the risk of developing injuries. Of these, the lower quarter Y-Balance Test (YBT) and Star Excursion Balance Test (SEBT) are similar measures of dynamic balance that have been extensively studied in athletes. Ruffe et al found that the YBT predicted ROI occurrence in male high school XC runners. Additionally, Smith et al found that the YBT predicted noncontact injury occurrence among NCAA Division I student-athletes. However, XC and track & field athletes accounted for only 22% of all participants. Thus, clinicians have worked with an incomplete pool of data to develop specific, evidence-informed injury screens for collegiate runners.

The purpose of this study was to investigate whether a preseason clinical assessment of dynamic balance, through a modified version of the YBT (mYBT), can predict risk of ROIs during one NCAA Division I XC season.

METHODS

DESIGN

The study utilized a prospective case-control design, approved by the University of South Dakota Institutional Review Board. All participants completed an informed consent form prior to participation. All rights of participants were protected.

SUBJECTS

Male and female student-athletes on the Division I XC team at a Midwestern University were recruited to participate in this study between August to November 2018. Exclusion criteria included: (a) having an injury within the prior six months that prevented the participant from running, (b) pregnancy, (c) under 18 years old, (d) non-English speaking, and (e) having a known balance impairment (e.g. unresolved head injury, vertigo, recent head cold, etc.).

INSTRUMENT

A modified version of the lower quarter Y-Balance Test (mYBT) was tested using the YBT Kit (Functional Movement Systems, VA, USA). During the original test, the participant maintains balance on one leg (tested leg), while reaching their opposite leg as far as they can in three directions: anterior (AN), posteromedial (PM), and posterolateral (PL). In this study, a fourth reach direction, posterior (PO), was added and termed the modified version of the YBT (Figure 1). The original lower quarter YBT has moderate to very high intra-rater reliability (ICC=0.68-0.94) and high to very high inter-rater reliability (ICC=0.73-1.00). The AN, PM, and PL reach directions have minimal detectable changes (MDC) of 5.87%, 7.84%, and 7.55%, respectively.

PROCEDURES

Demographic information was collected via questionnaire. Participants performed a five-minute, moderate intensity warm-up on a stationary bicycle, then partook in two clusters of preseason testing. The first test cluster included static balance, isometric hip strength, and isometric ankle strength. Data for the first test cluster were part of a larger study but were not analyzed in this report. Therefore, further details of the first cluster have been omitted. The second test cluster included three stations: (a) mYBT-AN and PO, (b) mYBT-PM and PL, and (c) leg length measurement. For both clusters, participants were randomly allocated to the first station, then proceeded through the subsequent
stations in stepwise fashion.

During mYBT testing, participants were instructed to place their tested foot on the center platform with hands on their hips, then use their contralateral toes to slide the reach platform as far as possible, then return to starting position while maintaining balance throughout the entire motion. Errors, such as lifting hands away from hips, placing too much pressure or bearing weight on the reach leg, excessively pushing the reach platform, and lifting the heel of the stance foot, were not scored. Participants were given two practice trials followed by three scored trials in each reach direction. Right and left legs were tested in random order.

Scores (Table 1) were categorized by limb dominance: dominant (DO) and nondominant (ND), defined by the questionnaire as "which leg do you use to kick a soccer ball?" For each leg, the average of three scored trials in each direction was calculated to obtain a raw reach score (R). These were further normalized to leg length to create normalized scores (N). A traditional YBT composite score (CS) was calculated for analysis using the equation \([\text{Normalized \(\text{AN} + \text{PM} + \text{PL}\)}]\). Raw difference (RD) was calculated using the equation \([\text{ABS} (\text{raw DO – ND})]\). Percent limb asymmetry (%LA) was calculated using the equation \([\text{ABS} (\text{normalized DO – ND})]/[\text{MAX} (\text{normalized DO, ND})]\).

**INJURY SURVEILLANCE**

After preseason testing, participants engaged in their usual routine with the XC team. ROIs were logged by the athletic training staff, who were blinded to participant test scores, using weekly injury reports over the entire XC season. Injury reports included the injury diagnosis and participation status of each injured runner. Participation status was categorized into four groups, in order from least to most severe restriction: "full go," "as tolerated," "modified/limited," and "out." In essence, this weekly categorization corresponded to minimal, mild, moderate, and severe injuries, respectively. In order to be classified under "ROI" for this study, the participant must have been listed as: (a) "as tolerated" for two or more consecutive weeks, or (b) "modified/limited" or "out" for one or more weeks.

**DATA ANALYSIS**

IBM SPSS Statistics 27.0 (IBM, NY, USA) was used to analyze data. Normality of descriptive statistics was tested using the Shapiro-Wilk test. A receiver operating characteristic (ROC) curve analysis was performed to determine the ability of mYBT scores to predict injury, which included raw and normalized scores for each reach direction, CS, RD, and %LA. Area under the curve (AUC) values were used to determine the effectiveness of each test using the following categories: 0.50-0.69 (negligible), 0.70-0.79 (acceptable), 0.80-0.89 (excellent), and 0.90-1.00 (outstanding). Statistical significance was set at \(\alpha = 0.05\). Optimal cut-off scores and relative risk (RR) with 95% confidence intervals (CI) were calculated for relevant tests. A secondary analysis by sex was also conducted.

**RESULTS**

Data from twenty-nine of 31 XC runners (mean age = 19.66 ± 0.974; 66% female, 100% right-dominant) were analyzed. One runner was excluded due to leaving the team mid-season (unrelated to injury) and another was disqualified due to exerting excessively abnormal effort during testing. Nine (5 female, 4 male) of 29 runners sustained an ROI during the XC season. No significant differences in demographics were found between injured and uninjured runners (Table 2).

Mean (SD) normalized YBT scores are listed in Table 3. Five tests (Table 1) demonstrated the ability to predict ROI during one XC season: normalized posterior reach score of the nondominant limb (\(p = 0.03\)), raw difference and percent limb asymmetry of anterior reach (\(p = 0.01\)), and raw difference and percent limb asymmetry of posteromedial reach (\(p = 0.02\)). AUC, optimal cut-off scores, and relative risk (RR) ratios for the three tests are listed in Table 4 and described below. Other tests, including raw scores, composite scores, and raw differences, did not predict injury.

**NORMALIZED POSTERIOR REACH SCORE OF THE NONDOMINANT LIMB (N-ND-PO)**

In all runners, N-ND-PO was an acceptable predictor of injury (AUC = 0.756, \(p = 0.05\)). Runners who scored below 0.935 were 1.90 times more likely to sustain an ROI compared to those who scored above 0.935.

**ASYMMETRY OF ANTERIOR REACH**

In all runners, RD-AN and %LA-AN were excellent predictors of injury (AUC = 0.808, \(p = 0.01\)). Runners who had greater than 2.5 cm raw difference or 5.4% limb asymmetry with a normalized anterior reach were 5.73 and 7.78 times more likely to sustain an ROI compared to those who had
Table 2. Demographic information of participants (n=29).

<table>
<thead>
<tr>
<th></th>
<th>Uninjured (n=20)</th>
<th>Injured (n=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)*</td>
<td>19.85 ± 0.93</td>
<td>19.22 ± 0.97</td>
</tr>
<tr>
<td>Sex (% female)*</td>
<td>70%</td>
<td>56%</td>
</tr>
<tr>
<td>Height (cm)*</td>
<td>170.64 ± 9.11</td>
<td>168.20 ± 11.90</td>
</tr>
<tr>
<td>BMI (kg/m^2)*</td>
<td>20.33 ± 1.53</td>
<td>21.05 ± 1.33</td>
</tr>
</tbody>
</table>

*No significant differences were found between groups (P > .05).

Table 3. Average normalized mYBT scores.

<table>
<thead>
<tr>
<th></th>
<th>Average Score</th>
<th>Expected % Asymmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior (AN)</td>
<td>0.665 ± 0.057</td>
<td>3.9%</td>
</tr>
<tr>
<td>Posterior (PO)</td>
<td>0.915 ± 0.138</td>
<td>4.9%</td>
</tr>
<tr>
<td>Posteromedial (PM)</td>
<td>1.101 ± 0.073</td>
<td>3.8%</td>
</tr>
<tr>
<td>Posterolateral (PL)</td>
<td>1.055 ± 0.076</td>
<td>3.6%</td>
</tr>
<tr>
<td>Composite ([AN + PM + PL])</td>
<td>2.821 ± 0.175</td>
<td>2.3%</td>
</tr>
</tbody>
</table>

Abbreviations: mYBT, modified Y-Balance Test.

Table 4. ROC curve analysis of mYBT with relevant cut-off scores and relative risk ratios.

<table>
<thead>
<tr>
<th></th>
<th>AUC</th>
<th>Cut-off</th>
<th>RR (95% CI)</th>
<th>Sn;Sp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Scores</td>
<td>0.450-0.683</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Normalized</td>
<td>0.467-0.583</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Normalized Score</td>
<td>0.756*</td>
<td>0.935</td>
<td>1.90 (1.24,2.91)</td>
<td>1.00;0.50</td>
</tr>
<tr>
<td>Composite Score</td>
<td>0.506-0.553</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Raw Difference-PO, PM, PL</td>
<td>0.408-0.578</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Raw Difference-AN</td>
<td>0.808†</td>
<td>2.5 cm</td>
<td>5.73 (1.44,22.79)</td>
<td>0.78;0.80</td>
</tr>
<tr>
<td>Raw Difference-PM (♂)</td>
<td>0.958*</td>
<td>5.2 cm</td>
<td>5.00 (0.87, 28.86)</td>
<td>1.00;0.83</td>
</tr>
<tr>
<td>%LA- PO, PM, PL</td>
<td>0.397-0.589</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>%LA- AN</td>
<td>0.808†</td>
<td>5.4%</td>
<td>7.78 (2.00,30.32)</td>
<td>0.78;0.90</td>
</tr>
<tr>
<td>%LA- PM (♂)</td>
<td>0.958*</td>
<td>5.1%</td>
<td>5.00 (0.87, 28.86)</td>
<td>1.00;0.83</td>
</tr>
<tr>
<td>%LA- CS</td>
<td>0.658</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Abbreviations: mYBT, modified Y-Balance Test; AUC, area under the curve; RR, relative risk; Sn, sensitivity; Sp, specificity; AN, anterior; PO, posterior; PM, posteromedial; PL, posterolateral; CS, composite score; ND, nondominant; %LA, percent limb asymmetry.

* Indicates a significant correlation (p < 0.05).
† Indicates a significant correlation (p < 0.01).

less than 2.5 cm or 5.4% limb asymmetry, respectively.

ASYMMETRY OF POSTEROMEDIAL REACH

In male runners, RD-PM and %LA-PM were outstanding predictors of injury (AUC = 0.958, p = 0.02). Male runners who had greater than 5.2 cm raw difference or 5.1% limb asymmetry with posteromedial reach were 5.00 times more likely to sustain an ROI compared to those who had less
DISCUSSION

The results of this study suggest that specific measures within the mYBT can predict injury risk over one XC season. They include asymmetries for anterior and posteromedial reach and normalized posterior reach score. However, traditional composite scores do not predict injury risk in collegiate runners.

Anterior reach asymmetry (%LA and RD) demonstrated the ability to predict injuries over one collegiate XC season. This finding reinforces conclusions made by other authors. Smith et al.\(^\text{16}\) also identified AN asymmetry surpassing a 4 cm cutoff as an effective test among a mixed cohort of DI athletes. Yet Ruffe et al.\(^\text{15}\) found that a predetermined 4 cm cutoff between limbs did not predict injury in high school XC runners. In the current study, the optimal cutoff was identified at a slightly lower value of 2.5 cm. This peculiar finding might be explained by leg length relativity. Runners (168-170 cm and 167 cm)\(^\text{15}\) were shorter than a mix of DI athletes (174-180 cm),\(^\text{16}\) which presumes that their legs were shorter. It is possible that the runners’ raw reach difference values were diminished by their shorter legs. Thus, the raw difference cutoff value may depend on leg length. Normalizing differences to leg length improved the test’s ability to detect meaningful asymmetries in runners, even though they were shorter. Therefore, AN asymmetry is a better predictor for runners when scores are normalized and compared to relative potential.

Posteromedial reach asymmetry (RD and %LA) also predicted injuries among collegiate male runners. Ruffe et al.\(^\text{15}\) also reported that PM asymmetry ≥ 4 cm increased injury risk in high school male XC runners (AOR = 5.05, 95% CI: 1.3, 19.8). It is noteworthy that two independent investigations only found this pattern among male runners. Hertel et al.\(^\text{32}\) found that PM reach asymmetry in the SEBT was detected in people with chronic ankle instability, which suggests it has the ability to discriminate dysfunctional movement. Compared to AN reach, PM reach increases triplanar demands from the hip and core.\(^\text{33}\) Also, hip adductor muscles may be more stressed. Unfortunately, adductors have not been investigated in EMG studies. Compensatory biomechanics during the YBT, such as knee valgus and trunk lean, have also been suggested to better explain asymmetries (or lack thereof),\(^\text{15}\) but have not been well documented in research. Regardless of pathomechanical rationale to support these findings, this is the second clinical study to support the value of PM asymmetry in male runners.

Both raw reach difference and percent limb asymmetry were identified as predictors of injury for AN and PM reach. While RD values (2.5 cm and 5.2 cm, respectively) were different, %LA values (5.4% and 5.1%, respectively) were much more similar. The similarity of %LA values may afford clinicians convenience and consistency by applying a relative cutoff standard of 5% for both reach directions.

The original YBT does not include a reach in the posterior direction. The authors are unaware of any scientific studies that validate the distinction of only three reach directions used in the YBT, compared to eight directions originally included in the SEBT. This study is the first to validate the use of normalized PO reach in the mYBT for screening...
ROIs. Testing PO reach appears to be biomechanically sound, since runners mostly function in the sagittal plane with an emphasis on hip extensors. During the SEBT, a PO reach increases the biomechanical demands on the spinal extensors and gluteus maximus more than AN reach. Thus, PO reach may mimic running better than AN reach. Furthermore, testing PO reach does not require additional equipment or cost. The runner simply turns around to face away from the AN reach platform. Due to the potential for injury prediction and negligible cost, there is added value in testing normalized PO reach for collegiate runners.

Finally, composite scores have been inferred to predict injuries in some studies but not others. Plisky et al. and Butler et al. found that CS was predictive of injuries in basketball and football players, respectively. These sports involve rapid, triplanar movements. However, CS did not have the same predictive value when a variety of collegiate athletes were grouped together. Furthermore, CS did not predict injuries among high school runners and collegiate runners in the current study. Therefore, CS appears to have greater value in predicting risk in sports with triplanar demands. Since running is a sagittal plane sport, composite scores may not be catered toward a runner’s demands.

LIMITATIONS

A small sample size limits the generalizability of the results. The test performance and injuries were recorded on a group of collegiate runners who were probably more fit than average runners. They were also subjected to training programs that involved high training loads and rapid progressions. For the preseason testing protocol, runners tested static balance, ankle and hip strength for approximately 30 minutes prior to testing mYBT, so fatigue may have impacted their mYBT scores. Runners were only given two practice trials in order to offset fatigue and time constraints, though six practice trials have been recommended to stabilize performance. However, the actual impact of reducing practice trials within a comprehensive injury screen is unknown. Another limitation is that ROIs are subjective in nature, so injury reporting patterns may have been influenced by various uncontrollable factors over the course of the season.

These reports may have affected the results, but such inherent risks were no different than a typical collegiate sports medicine setting.

Future studies should include multicenter trials with several collegiate XC programs in order to improve generalizability of mYBT results to any collegiate runner. A larger pool of runners could factor age, sex, injury history, experience level, previous training, and fitness within the injury analysis. Further biomechanical analysis, including hip adductor electromyography, should be performed in runners to help explain pathomechanics of this specific injury screen.

CONCLUSION

Specific components of the mYBT, including anterior reach asymmetry, posteromedial reach asymmetry, and normalized posterior reach score, are valid tests in predicting the risk of collegiate runners developing an ROI over one Division I XC season. Thus, the mYBT is a viable test to include within preseason injury screening for collegiate runners. Clinicians should consider a 5% limb asymmetry cutoff for AN and PM, in addition to a 0.935 normalized, nondominant limb cutoff score for PO, as ROI risk factors.

DISCLAIMERS

The authors have no financial disclosures to report.

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REFERENCES


The Reliability and Validity of Gluteal Endurance Measures (GEMs)

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Keywords: gluteals, endurance, electromyography, movement system

Background
The gluteals have unique morphology related to muscle endurance, including moderate fiber sizes and a majority of Type I endurance fibers. Evidence suggests gluteal endurance is related to low back pain, running kinematics, balance, posture, and more. However, reliable and valid measures specific to gluteal endurance are lacking in the literature.

Hypothesis/Purpose
The purpose of this study was to examine the intra- and inter-rater reliability of two gluteal endurance measures (GEMs) for clinical use. It also aimed to examine validity for the two measures by using electromyography (EMG), recording reasons for task failure, and analyzing differences between demographic groups.

Study Design
Cross-Sectional

Methods
Sixty-eight males and females with and without recurrent low back pain aged 18-35 years were recruited from a university population. Electromyography electrodes were placed on subjects’ gluteus maximus and gluteus medius, and each subject performed three trials of GEM-A (abduction endurance) and GEM-B (bridging endurance). Hold times, EMG median frequency (MF) data, and subjective reasons for task failure were analyzed.

Results
Both GEMs demonstrated high intra-rater reliability (ICC = 0.87-0.94) and inter-rater reliability (ICC = 0.99). Mean hold times were 104.83 ± 34.11 seconds for GEM-A (abduction endurance) and 81.03 ± 24.79 seconds for GEM-B (bridging endurance). No statistically significant difference was found between subjects with and without recurrent LBP. Median frequency data validated the onset of gluteal fatigue during both measures. Posterolateral hip (gluteal) fatigue was reported as the primary reason for task failure in 93% and 86% of subjects for GEM-A and GEM-B, respectively.

Conclusion
This seminal study of GEM-A (abduction endurance) and GEM-B (bridging endurance) found both measures to be reliable and valid measures of gluteal endurance. Further examination of the GEMs in samples with different types of LBP or hip pain is recommended.

Level of Evidence
3
INTRODUCTION

In 1999, McGill et al. published a study of clinical targets and reliabilities for submaximal isometric trunk endurance exercises in a healthy university population. These exercises included isometric trunk flexion, trunk extension, and side bridge exercises held to fatigue. Since that seminal study, those endurance measures have been used to determine endurance deficits in several specific populations, notably subjects with varied classifications of low back pain. McGill and others recognized the need to measure muscle endurance as a construct separate from muscle strength, a distinction especially evident in core muscles including the gluteals.

The gluteals have unique morphology related to muscle endurance. The gluteus medius is composed of about 58% Type I fibers, fibers with high oxidative capacity oriented for endurance. The gluteus maximus is composed of about 52–68% Type I fibers. Most muscles display a combination of fiber types, but the gluteals have a larger percentage of Type I fibers than several other lower limb muscles including the rectus femoris (38%), vastus lateralis (42%), and gastrocnemius (48%). In another cadaveric study, the gluteals were shown to have a moderate fiber size, neither small nor large, again reflecting their purpose for both strength and endurance activities.

Time to failure of the side bridge is frequently used to assess lateral trunk endurance. It has been inversely correlated to the development of low back pain (LBP) during standing. LBP in tennis players, LBP in female university dance students, work-related musculoskeletal disorders in manual lifting workers, peak internal rotation during running in female runners, and static balance during single-limb stance in male university students. The side bridge has been shown to elicit high gluteus medius electromyographic (EMG) activity (74% MVIC) and low gluteus maximus activity (21% MVIC). At the same time, it elicits considerable activity from the external oblique (69% MVIC) and other trunk muscles. The adductor muscles also likely assist in keeping the pelvis lifted from the ground, although their contribution has not been measured via EMG. In a study by Greene et al., subjects performing the side bridge as a test of endurance were asked their reasons for task failure and less than 50% cited side or hip fatigue or pain as the primary cause. Over 40% reported upper extremity fatigue or pain as their reason for failure during the side bridge. This indicates that although the side bridge elicits high EMG activity of the gluteus medius, it has limited specificity to gluteal endurance.

The supine bridge, a common measure of posterior trunk endurance, has been shown to elicit both gluteus maximus and gluteus medius EMG activity, but at low levels (25% and 28% MVIC, respectively). Another limitation of the supine bridge as a measure of gluteal endurance is its use of bilateral lower extremities. This bilateral activity offers little information for determining unilateral endurance deficits. Time to failure of the supine bridge has, however, been correlated to chronic mechanical back pain, pain and disability in patients with lumbar spondylolisthesis. The EMG activity of a unilateral bridge with the knee flexed to 90° has been examined in multiple studies, and ranges from 40–51% MVIC for the gluteus maximus and 47–57% MVIC for the gluteus medius. The unilateral bridge with the knee flexed to 90° has been examined as an endurance task in one study. However, it was performed only by a relatively small sample size (n=20) of healthy subjects and no reliability data were calculated. Also, the unilateral bridge with the knee flexed to 90° has been shown to elicit higher hamstring activity (up to 75% MVIC) than gluteal activity, causing the hamstrings to likely be the limiting muscle during the unilateral bridge, instead of the gluteals. The side and supine bridges have value as endurance measures; however, treatment for endurance deficits could be better targeted if the endurance measures implemented were targeted to a specific muscle group rather than several muscle groups.

Gluteal endurance appears related to several classifications of low back pain, work-related musculoskeletal disorders, running kinematics, balance, and pelvic posture. Given the morphology of gluteal muscles related to endurance, the lack of clinical endurance measures specific to the gluteals, and the link between various pathologies or impairments and gluteal or trunk endurance, the purpose of this study was to examine the intra- and inter-rater reliability of two gluteal endurance measures (GEMs) for clinical use. It also aimed to examine validity for the two measures by using electromyography (EMG), recording reasons for task failure, and analyzing differences between demographic groups. It was hypothesized that GEM scores would demonstrate high intra- and inter-rater reliability, demonstrate highly reliable and negative median frequencies (demonstrating gluteal fatigue), and have lower standard errors of measurement (SEMs) than related measures. It was also hypothesized that the majority of subjective reasons for task failure would be posterolateral hip (gluteal) fatigue for both GEMs, and that subjects with recurrent LBP would have lower GEM scores than subjects without recurrent LBP.

METHODS

Male and female students between the ages of 18 and 35 years (23 male, 45 female; average age 22.78 ± 2.47 years; average BMI 23.59 ± 12.68 kg/m; average activity level 147.01 ± 111.03 minutes of moderate aerobic activity and 90.51 ± 81.75 minutes of vigorous aerobic activity per week) were recruited with emails and word-of-mouth from a local university. Both undergraduate and graduate students in health-related fields volunteered. Exclusion criteria were adapted from a similar study of muscle endurance by Shelbourn et al.: a history of angina or emphysema; diagnosed spinal or hip abnormality; abdominal, back, or lower extremity surgery within the past year; or pregnancy. Subjects recruited with a history of recurrent LBP denied pain on the day of testing. Estimating a prevalence of recurrent LBP of 24% based on a study by Stanton et al., subjects were recruited. Of those 68 subjects, 51 presented without recurrent LBP (16 male, 35 female) while 17 reported recurrent LBP (6 male, 11 female). This sample size, accommodating for a 10% drop-out rate, was based on the number needed to detect a large effect size of 0.8 with a study power of 0.8 and an alpha level of 0.05.
The study was conducted in a biomechanics laboratory at a local university. Institutional Review Board approval was acquired prior to subject recruitment. Subjects arrived in exercise attire and first completed a consent form, current health history questionnaire, and activity and demographics questionnaire. Age, height, weight, sex, leg dominance, and average weekly aerobic activity were recorded on the activity and demographics questionnaire. Subjects were introduced to the testing procedures, including the specifics of the GEMs, familiarization trial, electrode placement, and rest periods.

Surface EMG electrodes were used to record muscle activity as the subjects performed the GEMs. Before electrode placement, the skin over the gluteals was cleaned and abraded with alcohol wipes by the subjects following instruction of the procedure. Surface electrodes were placed by subjects in a private room following researcher instruction, then appropriate placement was confirmed by the lead researcher via palpation over the subjects’ clothing. Bipolar electrodes were placed on the gluteus maximus and gluteus medius of the dominant leg as determined by which leg would be used to kick a ball. Electrode placement was based on related studies and standard practice. A ground electrode was placed over the ipsilateral anterior superior iliac spine. The electrode to record gluteus maximus activity was placed midway between the lateral border of the sacrum and the posterosuperior edge of the greater trochanter on the muscle belly. The electrode to record gluteus medius activity was placed anterosuperior to the gluteus maximus, inferior to the lateral aspect of the iliac crest on a line towards the greater trochanter on the muscle belly. Surface EMG data were collected at 3000 Hz using a Noraxon TeleMyo 2400T GT (Noraxon, Scottsdale, AZ).

The order of GEM-A (Figure 1) and GEM-B (Figure 2) performance was determined via coin flip. Descriptions of GEM-A and GEM-B are provided in Table 1. The GEMs were only tested in the dominant lower extremity as there was no significant difference in hold time or MF slopes between sides in studies of similar core endurance tasks. Following familiarization of each position, three trials of each of the two GEMs were performed with 10 minutes of rest between each trial. Rest durations for similar endurance tasks in other studies vary, including a minimum of five minutes between repetitions and a 1:4 work-to-rest ratio. Preliminary testing revealed noticeable decreases in GEM scores between the first and third repetitions of each measure when five minutes of rest were provided, but no significant differences existed between trials when 10 minutes of rest were provided between repetitions. The lead researcher was blind to the GEM scores (times to task failure recorded in seconds) as a lab technician started and stopped the EMG software upon verbal direction while the lead researcher monitored each subject. Subjects were asked “Why did you stop the test?” immediately following each trial, and their reasons for task failure were recorded in an electronic spreadsheet by the lead researcher. This question was identical to the question used in a study of side bridge variations by Greene et al.

The minimum number of subjects needed for reliability analysis was determined for a desired power of 0.8, an alpha level of 0.05, three repeated measures for intra-rater reliability, and three repeated measures for inter-rater reliability. The anticipated intra-rater reliability of GEM scores (recorded in seconds) was 0.9 based on the largest study of the side bridge’s reliability. Using a method described by Walter et al. and the aforementioned values, it was determined that at least 13 subjects were needed for intra- and inter-rater reliability analysis. Therefore, 13 healthy subjects and 13 subjects with recurrent LBP were video-recorded performing the GEMs. Recurrent LBP was defined as two or more episodes of LBP lasting more than 24 hours with a numeric pain rating scale (NPRS) score of more than 2/10 within the past year, and with at least a 30-day pain-free period between episodes. These video recordings were taken consecutively from the start of the study until 13 subjects from each group were recorded. A second researcher used the recordings to determine time to task failure of the GEMs. These data were used for inter-rater reliability analysis. The recordings were muted to blind the second researcher from the verbal direction used between the lead researcher and lab technician. The second researcher was blinded to all subject data besides the muted recording, including group assignment and time to task failure recorded by the lead researcher on the EMG software.

Surface EMG data were collected at 3000 Hz, rectified, and filtered using a 4th order Butterworth filter with a pass-band between 5 and 500 Hz. Median frequency was calculated within a one-second moving window every 100 milliseconds (ms). Time to task failure of the GEMs was recorded for all subjects using the EMG software program.

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**Figure 1. Gluteal endurance measure A (GEM-A) – abduction endurance**

**Figure 2. Gluteal endurance measure B (GEM-B) – bridging endurance**
Table 1. Descriptions of gluteal endurance measures (GEMs)

<table>
<thead>
<tr>
<th>GEM Title</th>
<th>GEM Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEM-A (abduction endurance)</td>
<td>The subject is sidelying with the back parallel to and lightly touching a wall for spatial reference. The hip and knee of the top lower extremity (the extremity being tested) are in 0° of flexion and rotation, resting on the bottom lower extremity. The bottom extremity’s knee is flexed to 90°, and its hip is flexed near 45° to allow the sole of the foot to rest on the posterior wall. Shoes are worn. The hand of the top arm rests lightly on the top iliac crest for pelvic monitoring. The bottom arm rests in a relaxed, comfortable position, and the subject’s head rests on a standard pillow with the trunk in a neutral position. The subject’s uppermost lower extremity is passively abducted by the tester to 30° as measured by an inclinometer. The tester then releases hold of the extremity and instructs the subject to actively maintain the hip in 30° of abduction as long as possible. The tester is allowed to give cues to the subject during testing to re-achieve correct positioning; however, no motivational cues are given. The tester monitors the subject’s position using a tape marker placed on the wall near the subject’s raised heel until the test ends. The subject is not told or able to see the time elapsed during until all testing is complete. The test ends when the tester observes an estimated loss of over 25% of the starting position height for more than three seconds, or the pelvis contacts the testing surface. The time to task failure is recorded.</td>
</tr>
<tr>
<td>GEM-B (bridging endurance)</td>
<td>The subject is hooklying with the arms across the chest. The tested extremity’s knee is flexed to 135° or as near to that position as able. The feet are placed shoulder-width apart. Shoes are worn. The non-tested extremity’s knee is extended to 0° of flexion, and its thigh is held parallel to the tested extremity’s thigh throughout the test by the subject. The subject is instructed to actively extend the tested extremity’s hip to 0° of flexion (or nearest to this position as possible) as measured by the tester using a goniometer. The subject is instructed to maintain the hip in 0° of flexion as long as possible. The tester is allowed to give cues to the subject during testing to re-achieve correct positioning; however, no motivational cues are given. The tester monitors the subject’s position until the test ends. The subject is not told or able to see the time elapsed until all testing is complete. The test ends when the tester observes an estimated loss of over 25% of the starting position height for more than three seconds, or the pelvis contacts the testing surface. The time to task failure is recorded.</td>
</tr>
</tbody>
</table>

The lead researcher used verbal "start" and "stop" directions while a lab technician simultaneously started and stopped data collection within the program. While watching recorded video, a second researcher used a stopwatch to record time to task failure of all GEM trials for the 26 subjects used for inter-rater reliability analysis (13 healthy subjects, and 13 with recurrent LBP). Subjective reasons for task failure were recorded after each trial on an electronic spreadsheet. Data were processed using custom written code (Matlab, The Mathworks, Natick, MA). The MF slope values were recorded in hertz per second (Hz/s). The times to task failure were recorded in seconds (s). SPSS v23.0 (SPSS Inc, Chicago, IL) was used for data analysis.

Intraclass correlation coefficients (ICC) were used to determine intra- and inter-rater reliability of the GEM scores and MF slopes. Traditional formulas were used to calculate standard errors of measurement (SEM) and minimal detectable changes (MDC) for GEM scores. Pearson’s correlation coefficients were used to determine the correlation between GEM scores, MF slopes, and body mass index (BMI). Independent t-tests were used to determine significant differences between subjects using the presence of recurrent LBP, sex, and BMI as independent variables on the dependent variables of GEM scores and MF slopes. Means and standard deviations were calculated for GEM scores and MF slopes. Frequency values were calculated for subjective reasons for task failure after categorizing each subject response as postero lateral hip (gluteal) fatigue, contralateral postero lateral hip fatigue, low back (rector spinae) fatigue, anterior thigh (quadriceps) fatigue, posterior thigh (hamstring) fatigue, or lower leg (triceps surae) fatigue. No subject reported pain as the primary reason for task failure, and all responses fell in one of the aforementioned six categories.

RESULTS

Sixty-eight subjects were measured. Data from 66 subjects were included, 49 healthy subjects and 17 subjects with recurrent LBP. Data from two subjects (females without recurrent LBP) were excluded due to faulty data from the EMG leads over the gluteals. Descriptive statistics for GEM scores are displayed in Table 2. Results include data from 22 males and 44 females with an average BMI of 23.39 ± 12.68 kg/m and age of 22.78 ± 2.47 years. Times from both GEMs demonstrated high intra- and inter-rater reliability (ICC = 0.87-0.94 and ICC = 0.99, respectively). The MF slopes for both gluteal muscles also demonstrated high reliability for each GEM (ICC = 0.74-0.82 for GEM-A; ICC = 0.70-0.83 for GEM-B). The standard errors of measurement (SEM) for GEM-A and GEM-B scores were 8.36 and 8.94 seconds, respectively. These SEM values equate to minimal detectable changes (MDC) of 23.17 and 24.78 seconds for GEM-A and GEM-B, respectively.

Pearson’s correlation coefficients between GEM scores, MF slopes, and BMI revealed multiple significant correlations. There was a significant correlation between GEM-B scores and both gluteus maximus and gluteus medius MF slopes (r = 0.35, p = 0.004; and r = 0.44, p = 0.000 respectively), indicating lower GEM-B scores as gluteal MF slopes become steeper in the negative direction (as muscle fatigue increases). There was a significant negative correlation between BMI and gluteus maximus MF slope during GEM-B (r = -0.24, p = 0.048), indicating subjects with a larger BMI have lower GEM-B scores. Lastly, GEM-A scores showed significant but low correlation with GEM-B scores (r = 0.32, p =
Table 2. Descriptive statistics for GEM scores (hold times)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Subject description</th>
<th>Mean ± SD (s)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEM-A (abduction endurance)</td>
<td>All subjects</td>
<td>104.83 ± 34.11</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>Healthy subjects</td>
<td>105.14 ± 36.37</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>Subjects with recurrent LBP</td>
<td>103.93 ± 27.53</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Males</td>
<td>92.46 ± 29.64*</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>111.01 ± 34.83*</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Subjects with BMI&lt;25</td>
<td>109.44 ± 33.35†</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>Subjects with BMI&gt;25</td>
<td>89.12 ± 30.71†</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Subjects with aerobic activity&gt;150 min/wk</td>
<td>106.05 ± 33.88</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>Subjects with aerobic activity&lt;150 min/wk</td>
<td>99.30 ± 33.19</td>
<td>12</td>
</tr>
<tr>
<td>GEM-B (bridging endurance)</td>
<td>All subjects</td>
<td>81.03 ± 24.79</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>Healthy subjects</td>
<td>81.68 ± 24.93</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>Subjects with recurrent LBP</td>
<td>79.15 ± 25.04</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Males</td>
<td>86.61 ± 21.70</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>78.24 ± 25.98</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Subjects with BMI&lt;25</td>
<td>83.66 ± 25.27</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>Subjects with BMI&gt;25</td>
<td>72.10 ± 19.70</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Subjects with aerobic activity&gt;150 min/wk</td>
<td>80.95 ± 23.19</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>Subjects with aerobic activity&lt;150 min/wk</td>
<td>81.40 ± 30.14</td>
<td>12</td>
</tr>
</tbody>
</table>

* = statistically significant between sexes (p = 0.036); † = statistically significant between body mass index groups (p = 0.035); BMI = body mass index; min = minutes; N = number of subjects; s = seconds; SD = standard deviation; wk = week.

Table 3. Frequency distribution of subjective reasons for GEM-A failure

<table>
<thead>
<tr>
<th>Subjective reason for task failure</th>
<th>Frequency (number; percentage) (N = 198)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterolateral hip (gluteal) fatigue</td>
<td>184; 92.93%</td>
</tr>
<tr>
<td>Contralateral posterolateral hip fatigue</td>
<td>7; 3.54%</td>
</tr>
<tr>
<td>Low back (erector spinae) fatigue</td>
<td>3; 1.52%</td>
</tr>
<tr>
<td>Anterior thigh (quadriceps) fatigue</td>
<td>2; 1.01%</td>
</tr>
<tr>
<td>Posterior thigh (hamstring) fatigue</td>
<td>1; 0.51%</td>
</tr>
<tr>
<td>Lower leg (triceps surae) fatigue</td>
<td>1; 0.51%</td>
</tr>
</tbody>
</table>

N = number of total trials

0.008).

Independent t-tests revealed few statistically significant differences between sexes, BMI groups, and those with and without recurrent LBP. Scores for GEM-A were significantly lower in males than females (p = 0.036). Similarly, MF slopes for the gluteus medius were significantly steeper in the negative direction for males (-0.31 ± 0.15 Hz/s) than females (-0.17 ± 0.10 Hz/s) during GEM-A (p = 0.000), indicating higher fatigability. Scores for GEM-A were also significantly lower in subjects with a BMI greater than or equal to 25 (defining overweight) than those with a BMI less than 25 (p = 0.035). No statistically significant differences were found between subjects with and without recurrent LBP.

Subjects reported posterolateral hip (gluteal) fatigue as the reason for task failure in 184/198 trials of GEM-A (93% of trials). Subjects reported posterolateral hip (gluteal) fatigue as the reason for task failure in 170/198 trials of GEM-B (85.86% of trials). The frequency distribution of subjective reasons for GEM-A and GEM-B failure are reported in Tables 3 and 4, respectively.

**DISCUSSION**

The purpose of this study was to determine the reliability of
Table 4. Frequency distribution of subjective reasons for GEM-B failure

<table>
<thead>
<tr>
<th>Subjective reason for task failure</th>
<th>Frequency (number; percentage) (N = 198)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterolateral hip (gluteal) fatigue</td>
<td>170; 85.86%</td>
</tr>
<tr>
<td>Posterior thigh (hamstring) fatigue</td>
<td>16; 8.08%</td>
</tr>
<tr>
<td>Low back (erector spinae) fatigue</td>
<td>12; 6.06%</td>
</tr>
</tbody>
</table>

N = number of total trials

Table 5. Reliability, means, and SEMs of GEMs and similar measures

<table>
<thead>
<tr>
<th>Endurance measure</th>
<th>Intra-rater reliability (ICC) [95% CI]</th>
<th>Mean score ± SD (s)</th>
<th>SEM (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEM-A (abduction endurance)</td>
<td>0.94 [0.92, 0.96]</td>
<td>104.8 ± 34.1</td>
<td>8.4</td>
</tr>
<tr>
<td>GEM-B (bridging endurance)</td>
<td>0.87 [0.80, 0.92]</td>
<td>81.0 ± 24.8</td>
<td>8.9</td>
</tr>
<tr>
<td>Side bridge:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Greene, 201218 (right); (left)</td>
<td>0.78 [NA];</td>
<td>75.1 ± 50.3</td>
<td>23.6</td>
</tr>
<tr>
<td>2. McGill, 19994 (right); (left)</td>
<td>0.91 [NA];</td>
<td>80.2 ± 51.4</td>
<td>15.4</td>
</tr>
<tr>
<td>3. Palmer, 201138 (right); (left)</td>
<td>0.96 [NA];</td>
<td>81.0 ± 34.0</td>
<td>6.8</td>
</tr>
<tr>
<td>4. Waldhelm, 201239 (right); (left)</td>
<td>0.74 [0.30, 0.92]; 0.96 [0.87, 0.99]</td>
<td>78.5 ± 28.7</td>
<td>14.6</td>
</tr>
<tr>
<td>Supine bridge by Shellenberg, 200719</td>
<td>0.84 [NA]</td>
<td>170.4 ± 42.5</td>
<td>17.0</td>
</tr>
<tr>
<td>Isometric test of hip abductors with 7.5% BW load by Van Cant, 201640</td>
<td>0.73 [NA]</td>
<td>88.4 ± 38.2</td>
<td>19.8</td>
</tr>
</tbody>
</table>

BW = body weight; CI = confidence interval; ICC = intraclass correlation coefficient; NA = not available; SD = standard deviation; SEM = standard error of measurement

and validity of two convenient, inexpensive, and unilateral gluteal endurance measures (GEMs), GEM-A (abduction endurance) and GEM-B (bridging endurance). Scores for both GEMs demonstrated high intra-rater and inter-rater reliability comparable to similar measures of core endurance such as the side bridge and supine bridge in other studies. Table 5 describes the reliability, mean scores, and SEMs of the GEMs and similar measures in adults from other studies. The SEM of GEM-A and GEM-B was lower than the SEM of similar measures in most comparable studies.1,18,19,38–40 Validity of the GEMs was primarily displayed with MF slope values and subjective reports of reasons for task failure.

The results of this study of GEMs indicate similarities and advantages of these measures compared to related tests. An earlier study by Van Cant et al.40 examined an isometric test of hip abductors with an ankle weight load equivalent to 7.5% of subjects’ body weight (BW). This is a relatively new endurance measure yet to be studied elsewhere. Among the submaximal, isometric endurance measures that are related to the gluteals and have reliability data, this test is most similar to GEM-A (abduction endurance). The positions and actions of the two measures are similar except for the external load and degree of hip abduction used during testing. The loaded test examined by Van Cant et al.40 employs 0° of hip abduction (with the lower extremity held above the testing surface) while GEM-A is performed with 30° of hip abduction above the testing surface. Preliminary GEM trials experimented with different angles of hip abduction. Hip abduction angles higher and lower than 30° (i.e. 45°, 15°, and 0°) resulted in hold times beyond five minutes in several subjects which would be inconvenient in the clinical setting. This may be the reason Van Cant et al.40 used an external load at 0° of hip abduction.

The SEM value found for GEM-A is advantageously low compared to similar measures. The 30° of abduction used and the decision not to use an external load for GEM-A appear defensible in light of comparison to the isometric test of hip abductors at 0° with a 7.5% BW load. The external load used by Van Cant et al.40 may be what produced notably lower reliability and SEM values for the aforementioned test at 0° (ICC = 0.73, and SEM = 19.8 seconds, respectively) compared to GEM-A (ICC = 0.94, and SEM = 8.4 seconds, respectively). An external load (i.e. an ankle weight around the ankle) is an abnormal addition to limb movement which could alter the limb’s proprioception. This may result in increased limb movement during attempted isometric contraction and less consistent hold times.

The SEM value found for GEM-B is also advantageously low compared to similar measures. The supine bridge is the endurance measure most similar in position to GEM-
B (bridging endurance) with studied reliability values. Data for the supine bridge studied by Shellenberg et al.\textsuperscript{19} are also limited to its seminal study. It differs from GEM-B by employing the use of bilateral lower extremities and 90° of knee flexion for its starting position versus the 135° used for GEM-B. The supine bridge’s use of bilateral lower extremities may give rise to its higher SEM (17.0 seconds) compared to that of GEM-B (8.9 seconds). The mean score and standard deviation of the bilateral supine bridge (170.4 ± 42.5) were roughly twice that of GEM-B (81.0 ± 24.8). Another reason the supine bridge might have demonstrated a higher standard deviation and SEM is its lack of muscle specificity compared to GEM-B given its lower degree of knee flexion. A study of the unilateral bridge demonstrated 75% MVIC EMG activity of the biceps femoris when the knee was flexed to 90° versus 25% MVIC when it was flexed to 135°.\textsuperscript{24} The authors suggest this was because the lower leg is more vertically aligned when the knee is flexed to 135° (more parallel with the ground reaction force vector at the foot), so the knee extensor moment and subsequent need for hamstring activity are reduced. The lower reliability and higher SEM of the supine bridge compared to GEM-B, therefore, may be because it presents a challenge for both the hamstrings and gluteals bilaterally rather than attempting to isolate unilateral gluteal activity.

Inter-rater reliability data for other core endurance measures are similar to those of the GEMs. Larsson et al.\textsuperscript{41} found high inter-rater reliability for the side bridge in soldiers (ICC = 0.99), Evans et al.\textsuperscript{42} found similarly high inter-rater reliability for the side bridge in athletes (ICC = 0.82-0.91), Bruce et al.\textsuperscript{43} found high inter-rater reliability in an examination of several core muscle endurance tests (ICC = 0.99-1.00), including a dominant and non-dominant lower extremity wall sit hold and horizontal trunk hold which were likely to elicit activity from the gluteus maximus among other lower extremity and trunk muscles.\textsuperscript{44} Therefore, the high inter-rater reliability found for the GEMs in this study (ICC = 0.99 for GEM-A, 0.99 for GEM-B) is consistent with other submaximal isometric endurance measures related to the gluteals.

The reliability of MF slopes found in this study support their use for measuring gluteal fatigue. Reliability data for MF slopes of the gluteals during endurance tasks are limited, but slope values of the erector spinae during an extension endurance task are available for comparison. The reliability of MF slope during assessment of erector spinae fatigue via the Sorensen test (a common submaximal endurance measure for the back extensors) was shown to be high in a study by Dederling et al. (ICC = 0.70-0.87).\textsuperscript{45} The current study demonstrated similarly high reliability of the MF slopes of the gluteals during both GEMs (ICC = 0.70-0.83), indicating MF slope can be used as a reliable value of gluteal muscle fatigue during the GEMs.

The mean MF slopes of the erector spinae in the aforementioned study by Dederling et al.\textsuperscript{45} of the Sorensen test (-0.12 to -0.07 Hz/s) were similar to but flatter than the mean MF slopes of the gluteus medius and gluteus maximus in the current study during GEM-A and GEM-B (-0.22 to -0.14 Hz/s, and -0.25 to -0.08 Hz/s, respectively). This comparison indicates that the gluteals fatigue during the GEMs at a faster rate than the erector spinae fatigue during the Sorensen test. No specific slope value indicates muscle fatigue aside from a slope in the negative direction. Rather, a steeper negative MF slope generally indicates greater muscle fatigability. Median frequency slope values below zero, seen in both gluteals during both GEMs, indicate the presence of muscle fatigue.\textsuperscript{46}

A study by Xiao et al.\textsuperscript{34} examined MF slopes of lower extremities during a unilateral bridge. However, 90° of knee flexion (instead of 135°) and arm placement on the ground (instead of across the chest) were used for the unilateral bridge, and gluteals were not included in the analysis. Regardless, MF slopes during the unilateral bridge with 90° of knee flexion and ground arm placement were -0.14 Hz/s for the erector spinae, -0.06 Hz/s for the rectus abdominus, and -0.12 Hz/s rectus femoris. The difference in extremity positions between the unilateral bridge used by Xiao et al.\textsuperscript{34} and the position of GEM-B in this study limits direct comparison, but indicates the erector spinae and other muscles may also fatigue during GEM-B. The subjective reasons for task failure during GEM-B (Table 4), however, indicate the erector spinae are not a primary source of perceived fatigue.

In addition to the negative MF slope values indicating gluteal fatigue during the GEMs, and significant gluteal MVIC EMG activity found in the positions used by the GEMs in previous studies, subjective reasons for task failure provide content validity for the GEMs.\textsuperscript{24,47} Of the 198 trials of GEM-A (three trials from 66 subjects), posterolateral hip (gluteal) fatigue was reported as the reason for task failure 95% of the time. Posterolateral hip (gluteal) fatigue was the reason for task failure 86% of the time for GEM-B. Both of these values demonstrate higher focus on the gluteal muscles than similar core endurance measures, including the side bridge, a modified side bridge, and the Sorensen test.\textsuperscript{18,48} In a study of the side bridge and a modified version with the feet elevated instead of the torso, Greene et al.\textsuperscript{18} asked subjects "Why did you stop the test?" immediately after each test, which is identical to the question asked to subjects following the GEM trials. Side or hip fatigue or pain was the primary reason for task failure during the side bridge in the study by Greene et al.,\textsuperscript{19} but it was only reported from 46% of the healthy university subjects. The primary reason for task failure during the feet-elevated version of the side bridge in the same study was higher than the traditional side bridge, reported from 68% of subjects.\textsuperscript{18} The most common reason for task failure in a study of the Sorensen test was reported as "fatigue" (as opposed to LBP) in 62.5% of a sample of 544 working-age men.\textsuperscript{48} While reasons for task failure are not reported in many studies of core endurance measures, it appears the GEMs are more specific to the gluteals than several similar measures.

Criterion validity for the GEMs remains questionable, but was provided to a small degree by the correlation between GEM scores and their respective MF slopes in the recent study. There was a significant albeit low correlation between GEM-B scores and both gluteus maximus and gluteus medius MF slopes (r = 0.35, p = 0.004; and r = 0.44, p = 0.000 respectively).\textsuperscript{49} Correlations between GEM-A scores and MF slopes for the gluteus maximus and medius were negligible and were not statistically significant (r = 0.11, p = 0.575; and r = 0.18, p = 0.145, respectively). These results suggest that steeper negative MF slopes of the gluteals are correlated to
lower GEM scores, but GEM-B scores are related to MF slope to a larger degree than GEM-A scores.

The low correlations between MF slope and GEM scores are understandable in light of studies that hypothesize reasons other than EMG variables for submaximal isometric task failure. These reasons primarily involve factors of central fatigue, including the perception of effort.50,51 One assumption made by attempting to measure peripheral fatigue using MF slope is that the decline in a muscle's force generating capacity is associated to the time to task failure. It appears, from this study, that this is true to some degree, but additional mechanisms contribute to task failure of the GEMs.

There were no identified differences between measured GEM scores for healthy subjects and those with a history of recurrent LBP. This is contradictory to other studies of core endurance in subjects with LBP and does not support the current study's hypothesis.8,19,28 The notable difference between this study and others, however, is the type of LBP studied. Subjects with recurrent LBP were recruited for this study while subjects with chronic LBP have been used by most studies of core endurance measures.5,11,28 Research does not provide much information about factors that predict recurrence in individuals who have recently recovered from an episode of LBP,52 which is why such subjects were examined in this study. A systematic review of the risk of recurrence of low back pain revealed a history of previous episodes of LBP was the only factor that consistently predicted recurrence of LBP.52 No subjects in the current study had LBP at the time of testing. So it may be that the differences in hold times seen between subjects with chronic LBP and healthy controls during the Sorensen test, supine bridge, and other core endurance measures are due to the presence of pain during testing rather than their history of low back pain. The difference may also be due to the amount of time such subjects endured their chronic LBP or its intensity compared to the subjects with recurrent LBP used in this study. Further study is needed to determine if the GEMs can be used to distinguish between healthy subjects and those with pathology, such as acute or chronic low back pain or hip pain.

Relationships between BMI and both MF slopes and GEM scores were seen in the current study. No statistically significant differences were seen between subjects with and without recurrent LBP, but BMI demonstrated a statistically significant positive correlation with gluteus maximus MF slope during GEM-B (r = 0.35, p = 0.004). Additionally, subjects with a BMI greater than or equal to 25 (delineating overweight) showed significantly lower GEM-A scores than subjects with a BMI less than 25. In a study of multiple endurance tasks (handgrip, shoulder flexion, and trunk extension exertions at varying MVIC levels), findings indicated the relationship between BMI and fatigability is task dependent.55 Study of the Sorensen test has found subjects with higher BMI fatigue faster during the endurance test.8 This is similar to the relationship between BMI and hold times seen during GEM-A.

Sex differences were also found for select GEM scores and MF slopes. Scores for GEM-A were significantly shorter in males than females, and males demonstrated higher glu- teus medius fatigability as measured by MF slope during GEM-A. Sex differences during submaximal isometric core endurance measures are not consistent, but males appear to demonstrate higher fatigability of their core muscles than females.8,25,54 This data trend was found in the GEMs. This may be due to sex-based differences in skeletal muscles, specifically their fiber-type composition and function. There appears to be a higher proportion of slower type-I and type-IIA fibers in females versus males that mirrors lower contractile velocities found in females versus males.55 These sex differences may be what resulted in shorter GEM scores and higher fatigability as measured by MF slope among males compared to females in the current study.

The mean scores of the GEMs (104.85 ± 34.11 seconds for GEM-A, and 81.03 ± 24.79 seconds for GEM-B) are comparable to similar measures of core endurance and allow for convenient clinical application. Mean scores of the side bridge in healthy adults range from 77.25 to 95.42 seconds.1,4,9,39 Mean bilateral supine bridge scores have been reported as 170.40 seconds.19 Mean GEM scores between one and two minutes allow them to be performed as part of a clinical assessment without dominating the assessment time or neglecting the endurance characteristics of the gluteals. Also notable is no adverse events occurred during administration of the GEMs and the required instrumentation is minimal. So these GEMs are safe measures that can be readily utilized by clinicians. Moreover, the GEMs are simple enough to be performed and monitored by clients or athletes without clinicians.

This study is not without limitations. Surface EMG carries inherent limitations. These include electrical cross-talk between underlying muscles (causing electrodes to detect activity from muscles besides those targeted) and electrical impedance from debris on the skin. Differences in subcutaneous tissue layers can affect EMG parameters. Given these differences, a normalized (relative) MF slope calculated using the initial MF instead of an absolute measure of MF slope may have demonstrated more significant differences. Every effort was made to control for these limitations by using consistent electrode placement and cleaning and abrading the skin with isopropyl alcohol pads prior to data collection.

The GEMs were studied in male and female university students in health-related fields with and without recurrent low back pain, so the application of results to other populations is limited. This university sample between 18 and 35 years of age can be considered generally more active than adults older than 35 years, those who are less concerned with physical activity, and those with more sedentary lifestyles. Therefore, mean GEM scores found in this study are likely higher than the general population. Also, data derived from subjects with recurrent LBP in this study are limited to that location and type of pain. Areas of future study for the GEMs include subjects with chronic LBP or hip pain. Subjects with various hip pathology including femoroacetabular impingement are hypothesized to have decreased GEM scores.56 A prospective study would also provide more insight about the construct validity of the GEMs and risk factors for various hip or low back pathology.
CONCLUSION

This seminal study of GEM-A (abduction endurance) and GEM-B (bridging endurance) found both measures to be reliable and valid measures of gluteal endurance. Both GEMs demonstrated high intra- and inter-rater reliability. The MF slopes of the gluteus maximus and gluteus medius during each measure also demonstrated high reliability. No significant differences were seen between subjects with and without recurrent low back pain. Validity for both GEMs was provided by the notable negative MF slopes of the gluteals during each measure. Validity was also found from the high percentage of subjects who reported posterolateral hip fatigue as the primary reason for task failure for each GEM (86-93%), and the tendency for females and subjects with lower BMI to have higher GEM scores than males and subjects with higher BMI, respectively. Further examination of the GEMs in samples with different types of LBP or hip pain is recommended. The GEMs are specific to gluteal fatigue and demonstrate low measurement error compared to similar measures. The findings of this study, therefore, allow these GEMs to be confidently used to measure gluteal endurance in clinical and athletic settings among other measures of gluteal function.

CONFLICT OF INTEREST

There are no potential conflicts of interests, including financial arrangements, organizational affiliations, or other relationships that may constitute a conflict of interest regarding the submitted work.

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REFERENCES


Comparison of Hip and Low Back Loads between Normal Gait, Axillary Crutch Ambulation and Walking with a Hands-free Crutch in a Healthy Population

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Keywords: joint reaction force, hands-free crutch, gait, axillary crutch

Background
Instead of using axillary crutches, using a hands-free crutch (HFC) has been associated with higher functional outcome scores. However, hip and back pain have been reported as side effects.

Purpose/Hypothesis
The purpose of this study was to compare range of motion and joint reaction forces at the hip and low back between HFC walking, normal walking, and standard crutch walking. It was hypothesized that hip joint reaction forces and low back joint reaction forces would be higher with HFC walking compared with normal walking and axillary crutch walking.

Study Design
Controlled Laboratory Study

Methods
Using 3D motion analysis and force plates, kinematics and ground reaction forces were measured in 12 healthy subjects during gait, crutch ambulation and HFC walking. Gait speed, hip and trunk range of motion, and hip and low back reaction forces, were compared using repeated-measures ANOVA.

Results
Gait speed during HFC ambulation was reduced 33% compared to crutch ambulation (P<0.001) and 44% compared to normal gait (p<0.001). Hip range of motion was reduced during both crutch conditions compared to gait (p<0.001). Trunk range of motion was greatest during HFC walking compared to both gait and crutch ambulation (p<0.001). Peak hip joint reaction force during HFC walking was 11% lower than during gait (p=0.026) and 30% lower than during crutch walking (p<0.001). Peak low back reaction force during HFC walking was 18% higher than during gait (p=0.052) but not different than during crutch walking.

Conclusion
Hip joint reaction forces during HFC walking did not exceed those during gait or axillary crutch ambulation. However, a reduction in hip motion using the HFC was associated with increases in trunk motion and low-back loading. These could be a cause for reports of low-back pain accompanying HFC usage.

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INTRODUCTION

Surgery or injury to the lower extremities may result in a non-weight bearing rehabilitation protocol for a period that may last anywhere between several days to several months. Solutions for mobility such as wheelchairs, crutches and many more, have been in use for many years. Axillary crutches, while being one of the oldest assistive devices, are still one of the most commonly used for partial- or non-weight bearing mobility. While axillary crutches are very simple to use and present an efficient and economical solution, problems with the use of these devices include the inability to use them in case of a concomitant upper extremity injury and the possible development of neuropathies to the brachial plexus after prolonged use. As an alternative, the hands-free crutch (HFC) has been designed to mimic the natural gait pattern as best as possible while unloading the shoulders and freeing the patient’s hands.

The HFC was initially designed in 1997. The designer sought a way to free the hands while returning to work and day-to-day activities more quickly after a leg injury. Other benefits of this design became apparent as patients with upper extremity injury or disability could utilize this type of crutch. As currently designed, this crutch is only suitable for below-the-knee injuries. However, ability of the lower extremity to attenuate ground reaction forces when wearing the HFC may be reduced, as shock absorption from the ankle and knee joints are effectively eliminated. This may explain reports of hip and back pain while using the HFC.

Many studies have documented the kinetics of axillary crutch ambulation. However, the primary focus of these studies was on the ground reaction forces on the weightbearing limb and none of these examined the loads at individual joints of the lower extremity or low back. To the authors’ knowledge, there have been no studies examining lower extremity kinematics and kinetics while walking with the HFC. The purpose of this study was to compare range of motion and joint reaction forces at the hip and low back between HFC walking, normal walking and standard crutch walking. Due to the reduced ability of the lower extremity to attenuate ground reaction forces while wearing the HFC, it was hypothesized that hip joint reaction forces, as well as low back joint reaction forces, would be higher with HFC walking compared with normal walking and axillary crutch walking.

METHODS

Three-dimensional kinematics and ground reaction forces were measured in 12 healthy subjects; 11 men, 1 woman, (age: 36±10 yr, height: 179.0±6.7 cm, weight: 83.1±5.8 kg) during normal gait, axillary crutch ambulation using a swing-through gait pattern and HFC walking (iWalk 2.0, Long Beach, CA, USA). To be included in this study, subjects needed to be free of injury to the lower extremity for at least six months and have no neurological or orthopedic disorders known to affect gait. This study was approved by the Northwell Health Institutional Review Board and prior to participation, all subjects provided informed consent.

Subjects walked at self-selected pace approximately five meters across the lab while a 10-camera motion capture system (BTS Bioengineering, Quincy, MA, USA) recorded kinematic data at 500 Hz. Six force plates (BTS Bioengineering, Quincy, MA, USA) simultaneously recorded ground reaction forces at 1000 Hz. Trials in which the foot did not land completely on the force plates or the subject altered their gait pattern to target the force plate were discarded and the trial was repeated until five successful trials were recorded for each of the three conditions.

Reflective markers were placed bilaterally over the calcaneus, second metatarsal, medial and lateral malleoli, lateral shank, medial and lateral femoral condyles, lateral thigh, greater trochanter, sacrum, anterior superior iliac spines and acromia. During the wearable crutch walking trials, six additional markers were placed on the proximal and distal ends of the HFC. The motion data were then filtered with a fourth-order Butterworth low-pass filter with a cutoff frequency of 6 Hz in order to eliminate any high frequency noise. Sagittal and frontal plane hip and trunk angles, as well as peak vertical ground reaction force (vGRF) and peak hip and low-back joint reaction forces during the stance phase, were calculated using specialized computer software (Visual 3D, C-Motion, Inc., Rockville, MD, USA).

Two-way repeated-measures ANOVA (three conditions by two sides) were used to compare stance phase hip and trunk ranges of motion, peak vGRF, peak hip joint reaction...
force and peak low-back reaction force, as well as gait velocity, across conditions (normal gait, crutch gait, HFC gait and side (left vs right). When significant main effects or interactions were found, paired t-tests were used to compare variables measured during each condition. Bonferroni corrections were applied to planned post-hoc comparisons where applicable. Based on gait testing in our lab, we expected to be able to detect a 7% change in peak hip joint reaction force with 80% power at p<0.05 using 12 subjects.

RESULTS

Gait speed while wearing the HFC was reduced 33% compared to crutch ambulation (0.8 ±0.5 vs 1.2±0.6 m/s, P<0.001) and 44% compared to normal gait (0.8±0.5 vs 1.4±0.5 m/s, p<0.001). Frontal and sagittal plane hip range of motion were both significantly reduced during both crutch conditions (axillary and hands-free) compared to normal gait (p<0.001, respectively). Trunk range of motion in both the sagittal and frontal planes was greater during stance while wearing the HFC compared to normal gait (p<0.001) as well as compared to using the axillary crutch (p<0.001) (Table 1).

The highest peak vGRFs were recorded during axillary crutch ambulation (p<0.05, respectively, vs. all other conditions). Peak vGRF while wearing the HFC was 50% lower than axillary crutch ambulation (p<0.001) and 12% lower than normal gait (p<0.001) (Figure 2).

Axillary crutch ambulation also generated the highest peak hip joint reaction forces (p<0.05, respectively, vs. all other conditions). Peak hip joint reaction force during HFC walking was 30% lower than during axillary crutch walking (p<0.001). Peak low back reaction force during stance on the hand-free crutch was greater than that during normal walking (18% difference, p=0.052) but not different from that during axillary crutch walking (1.4% difference p=1.00) (Figure 2).

DISCUSSION

As part or their rehabilitation protocol, some patients may be required to be non-weightbearing for anywhere between several days to several months. Developed as an alternative to axillary crutches, the HFC has been designed to mimic the natural gait pattern while unloading the shoulders and freeing the patient’s hands. This device may be particularly useful in assisting patients after injuries or surgeries to the foot or ankle. Additionally, the use of this device has been associated with increased activity levels during recovery and rehabilitation and improved outcome scores.7

To the authors’ knowledge, this is the first study to characterize the kinematics and kinetics of hand-free crutch ambulation and to compare gait biomechanics while walking in this novel assistive device to traditional axillary crutch ambulation and to normal gait. The main purpose of this study was to address the concern that eliminating the shock absorption from both the ankle and the knee on the injured limb may cause greater loads to be transferred to the ipsilateral hip. The results of this study show that peak vertical ground reaction forces and peak hip joint reaction forces were both lower while walking in the HFC compared to axillary crutch gait and normal gait. Therefore, although the ability of the lower extremity to attenuate external forces is reduced, HFC use does not seem to overload the hip.

Additionally, the peak low back reaction force during HFC walking was greater than normal gait but not different than axillary crutch ambulation. In conjunction with this, using the HFC decreased range of motion in the hip, which seems to have been compensated for by a concomitant increase in range of motion of the trunk during stance. The increased low back reaction force combined with the increased trunk range of motion while using this device may contribute to reports of acute low back pain, as observed by Rabani et al.7

While there are currently no published data characterizing the kinetics and kinematics of walking in the HFC, the results of the current study comparing axillary crutch ambulation with normal gait compare favorably with the results of Stallard et al. and Goh et al.3,8 Relative to normal gait, these previous studies observed 24.5% and 21.6% increases in vertical ground reaction forces, respectively, during swing-through crutch ambulation at a similar speed. The current study found no difference in speed between normal gait and crutch ambulation. However, there was a 25% increase in vertical ground reaction force during crutch ambulation. This is most likely due to the increased vertical momentum of the body as it swings through the crutches and lands on lower extremity. By contrast, HFC walking more closely resembles normal gait with no swinging motion and a reduction in ambulation speed. The decrease in vertical motion, as well as ambulation speed, most likely accounts for the reduction in vertical ground reaction force during HFC walking.

There were a few limitations to this study that need to be addressed. First, as gait speed between conditions was

Table 1. Comparison of hip and low back kinematics (mean±SD) across conditions

<table>
<thead>
<tr>
<th></th>
<th>Hands-Free Crutch (HFC)</th>
<th>Axillary Crutch (AC)</th>
<th>Normal Gait (NG)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sagittal Hip RoM (deg)</td>
<td>20.6±3.1</td>
<td>29.0±4.8</td>
<td>40.6±6.2</td>
<td>p&lt;0.001*†‡</td>
</tr>
<tr>
<td>Frontal Hip RoM (deg)</td>
<td>8.5±1.7</td>
<td>6.9±1.4</td>
<td>11.2±1.8</td>
<td>p&lt;0.001*‡</td>
</tr>
<tr>
<td>Sagittal Trunk RoM (deg)</td>
<td>10.8±2.7</td>
<td>8.9±2.7</td>
<td>2.4±0.3</td>
<td>p&lt;0.001*‡‡</td>
</tr>
<tr>
<td>Front Trunk RoM (deg)</td>
<td>11.6±2.1</td>
<td>3.7±1.0</td>
<td>3.7±1.4</td>
<td>p&lt;0.001*†</td>
</tr>
</tbody>
</table>

* = HFC vs NG; † = HFC vs AC; ‡ = NG vs AC

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Figure 2. While wearing the hands-free crutch, peak vGRF and peak hip joint reaction forces were significantly lower than axillary crutch ambulation or normal walking. Peak low back reaction force during stance while wearing the hand-free crutch was higher than that during normal walking.

not standardized, the reduction in peak forces while wearing the HFC may have been due to the significant reduction in gait speed compared to the other conditions. Although gait speed has been known to affect ground reaction and joint reaction forces, we chose not to standardize gait speed among conditions due to the fact that patients using these devices will tend to ambulate at speeds that are comfortable and safe for them. Therefore, not standardizing gait speed allows us to assess the biomechanics of ambulating with these devices in a more practical and realistic fashion. However, despite the reduction in gait speed, we still found increases in the low-back force as computed by inverse dynamics. Second, our subjects were given only about half an hour to acclimate to using the HFC. This most likely contributed to the reduced gait speed while walking with this device. With more acclimation time or more habitual use, gait speed, as well as the kinetic variables, may have been more similar to normal gait. Finally, this device was tested on a small population that was predominantly male. Increasing the number of subjects and including more females would give a clearer picture of the effects of the HFC on joint loads during gait.

CONCLUSIONS

The results of this study indicate that although gait speed was significantly affected while wearing the HFC, peak hip joint loads during HFC walking did not exceed those of normal gait or axillary crutch gait. Additionally, lower back reaction force during HFC walking was greater than normal gait but did not exceed that of axillary crutch gait. Therefore, HFC use during rehabilitation and recovery seems to be as safe as using axillary crutches with the added benefit of allowing the patient to use his or her upper extremities. However, the increased range of motion in the lower back may potentially lead to pain or discomfort in this area, and including balance and trunk stability training during the normal course of treatment and also in the initial stages of HFC use may reduce the incidence of pain or discomfort until the patient becomes acclimated to the device.

DECLARATION OF INTERESTS

Stephen J. Nicholas is a paid consultant for Arthrex, Inc.

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REFERENCES


Electromyographic Evaluation of Early-Stage Shoulder Rehabilitation Exercises Following Rotator Cuff Repair

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Keywords: rotator cuff, rehabilitation, range of motion, electromyography

Background
Electromyography (EMG) is frequently used as a guide for exercise rehabilitation progression following rotator cuff repair. Knowledge of EMG activity during passive and active-assisted exercises may help guide clinicians when considering exercise prescription in the early post-operative period.

Purpose
The purpose of this study was to investigate EMG activity of the rotator cuff and deltoid musculature during passive and active-assisted shoulder range of motion (ROM) exercises commonly performed in post-operative rehabilitation.

Study Design
Descriptive cohort laboratory study using healthy subjects.

Methods
In sixteen active healthy volunteers, surface and fine-wire EMG activity was measured in the supraspinatus, infraspinatus, subscapularis, and anterior, middle and posterior deltoid muscles during eight common ROM exercises. Mean %MVIC values and 95% confidence intervals were used to rank exercises from the least to the most amount of muscular activity generated during the exercises.

Results
Standard pendulum exercises generated low levels of EMG activity in the supraspinatus and infraspinatus (≤15% MVIC), while active-assisted table slides, and the upright wall slide generated low levels of EMG activity in only the supraspinatus. No exercises were found to generate low levels of muscular activation (≤15% MVIC) in the subscapularis.

Conclusion
This study found no clear distinctions between the EMG activity of the supraspinatus or the infraspinatus occurring during common passive and active-assisted ROM exercises. Subdividing ROM exercises based on muscle activity, may not be necessary to guide progression of exercises prior to commencing active motion after rotator cuff repair.

Level of Evidence
Level 3b
sensus states that rehabilitation after rotator cuff repair should include a two-week period of strict immobilization followed by a staged introduction of range of motion (ROM) activities, initially with protected, passive ROM (PROM) exercises to six weeks, followed by restoration of active ROM (AROM). However, the time in which certain exercises may be implemented, and progressed from PROM to AROM has been debated. This is especially important during the early post-operative stages, where loading should not exceed the biomechanical limits of the healing tissues, while still facilitating the alignment of newly formed collagen fibers.

Deciding on which exercises to prescribe in these first six weeks following repair is largely based on clinical opinion and patient feedback, with limited evidence regarding whether a particular exercise may be adversely loading the repair tissues. Muscular activity measured by electromyography (EMG) remains the best available direct estimate of stress placed on the rotator cuff tendon, to guide clinicians through appropriate exercise selection following cuff repair. In the earlier post-operative stages, a better understanding of how commonly employed PROM and active-assisted ROM (AAROM) exercises specifically load the rotator cuff would be of benefit to the therapist prescribing these activities to patients. The purpose of this study was to investigate EMG activity of the rotator cuff and deltoid musculature during PROM and AAROM exercises commonly performed in post-operative rehabilitation.

METHODS

PARTICIPANTS

A total of 16 physically active healthy volunteers (11 males, 5 females) with normal shoulder examination, no previous shoulder injury, and no pain with activities of daily living were recruited for this study. Participants were recruited using flyers on community notice boards and on social media platforms. Inclusion criteria for the study included participants 18 to 40 years of age, no previous shoulder injury or surgery to the dominant arm, no current shoulder pain, and the ability to demonstrate full active shoulder ROM. The study received approval from the University of Western Australia Human Research Ethics Committee (HREC), and all participants provided written informed consent prior to their study participation. This study conforms to all STROBE guidelines and reports the required information accordingly.

INSTRUMENTATION AND ELECTRODE INSERTION

Participants attended a single two-hour EMG testing session, whereby electromyographic data were collected simultaneously from six muscular locations around the dominant shoulder, using a combination of surface and indwelling fine-wire electrodes. A 16-channel telemetry EMG system (Myon 320, Myon AG, Zurich, Switzerland) sampling at 4000 Hz was used to record muscle excitations. The anterior deltoid, middle deltoid, and posterior deltoid were assessed with disposable, self-adhesive pre-gelled surface EMG electrodes (3M, Minnesota, USA), and placed on participants as described by Basmajian and De Luca.8 Electrode placements were confirmed by visualization of the EMG signal during active muscle activation, and all transition cells were secured with adhesive tape. Prior to electrode placement, the area was scrubbed with an abrasive sponge, then cleaned with isopropyl alcohol to reduce skin impedance. Intramuscular fine-wire electrodes were used to record muscle excitations of the supraspinatus, infraspinatus, and subscapularis. Using aseptic technique, the skin was prepared using a chlorohexidine solution. Intramuscular fine wire electrodes were inserted via a sterile 30 mm, 27-gauge hypodermic needle with a pair of 0.051 mm, insulated, bent end Teflon coated stainless steel wires and 200 mm tail with 5 mm bare-wire terminations (Chalgren Enterprises, USA) in accordance with the protocols described by previous studies. All electrode insertions were performed by a trained medical professional experienced in the practice. All fine wire insertions were guided by real time ultrasound (Teleemed Echo Blaster 128 EXT-1Z, TELEMED Medical Systems, Italy). The ultrasound unit was also used to confirm electrode placement, in concert with visual inspection of live EMG time traces during isometric contractions.

EXPERIMENTAL PROTOCOL

Prior to the commencement of data collection, participants were instructed to complete a brief warm-up by moving their arms through full active flexion and abduction ROM to ensure that the intramuscular electrodes had settled into position within the muscle, and the signal from each muscle was adequately detected. All participants underwent a familiarization session approximately one to two days before testing. During these sessions, each participant was given verbal and visual instruction of each exercise from a qualified Exercise Physiologist, upon which they subsequently practiced the exercise techniques and maximal voluntary isometric contraction (MVIC) protocols that will be discussed later.

EXERCISES

Eight ROM exercises, including four PROM and four AAROM, that are commonly prescribed during early rehabilitation following rotator cuff repair were included for evaluation in this study (Table 1, Figure 1). Active arm flexion and abduction were also evaluated against gravity to serve as a comparison with the PROM and AAROM exercises (Table 1, Figure 1). One set of six repetitions for each exercise was performed. A metronome was used to control arm speed, following a cadence of 15 beats per minute. Previous EMG studies have evaluated exercises at a speed of 60 beats per minute, with Gaunt et al8 in their study of active-assisted shoulder exercises, evaluated exercises at a speed of 30 degrees per second (approximately five beats per minute). Participants were given a 30 second rest between each trial to reduce fatigue effects. The order of these exercises was performed in a randomized fashion between participants to prevent order effects.

MAXIMAL VOLUNTARY ISOMETRIC CONTRACTION (MVIC)

Prior to the exercise testing session, participants were in-
Table 1. Descriptions of the four passive (PROM), four active-assisted (AAROM) and two active (AROM) exercises included in this study.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pendulum (Figure 1A)</td>
<td>PROM</td>
<td>Participant is standing and bent forward 90° at the waist, using the non-dominant hand to support themselves on a table for support. Participant has their dominant arm “hanging” down towards the ground at 90° of arm flexion and 0° of elbow flexion, circumducting the arm generated from the motion at the waist.</td>
</tr>
<tr>
<td>Rock the Baby – Circumduction</td>
<td>PROM</td>
<td>Participant is standing and bent forward 90° at the waist, supporting the dominant arm at the elbow with their opposite, non-dominant hand, at the elbow. Using the non-dominant arm, the dominant arm is guided and supported through circumduction through available range of motion.</td>
</tr>
<tr>
<td>Rock the Baby – Elevation</td>
<td>PROM</td>
<td>Participant is standing and bent forward 90° at the waist, supporting the dominant arm at the elbow with their opposite, non-dominant hand, at the elbow. Using the non-dominant arm, the dominant arm is guided and supported through arm flexion through available ROM.</td>
</tr>
<tr>
<td>Table Slide (Figure 1D)</td>
<td>PROM</td>
<td>Participant is in a seated position at a table, with their dominant hand of the dominant arm on a cloth placed on the table, set at elbow height, with the elbow at the midline of body. The participant slides their hand directly forward (toward full elbow extension) and backward in the sagittal plane, bending slightly forward with their body to achieve additional flexion ROM.</td>
</tr>
<tr>
<td>Pulley-assisted Elevation</td>
<td>AAROM</td>
<td>Participant is standing facing a wall with a rope and pulley attached to a door overhead. Holding on to either side of the pulley with both arms, the participant elevates their dominant arm by pulling down on the pulley with their non-dominant arm.</td>
</tr>
<tr>
<td>Assisted Wall Slide (Figure 1F)</td>
<td>AAROM</td>
<td>Participant is standing upright facing a wall, with the “dominant” hand resting at shoulder level on the wall in approximately 90° arm flexion, with the non-dominant arm supporting the dominant side at the elbow. The participant is then instructed to slide hand up and down the wall, using the non-dominant hand to assist this motion, going through full ROM.</td>
</tr>
<tr>
<td>Dowel-assisted Forward Elevation</td>
<td>AAROM</td>
<td>Participant is standing upright using the non-dominant arm to raise and lower the dominant arm into elevation, while grasping a broomstick for assistance, going through full arm flexion ROM.</td>
</tr>
<tr>
<td>Dowel-assisted External Rotation</td>
<td>AAROM</td>
<td>Participant is standing upright, with the dominant arm grasping one end of a broomstick, with the elbow placed at the side of the thorax. Having the non-dominant arm grasping the other end of the broomstick, the dominant arm is assisted into external rotation, going through full external rotation ROM.</td>
</tr>
<tr>
<td>Active Flexion</td>
<td>AROM</td>
<td>Participant is standing upright, and raises their dominant arm into full flexion ROM.</td>
</tr>
<tr>
<td>Active Abduction</td>
<td>AROM</td>
<td>Participant is standing upright, and raises their dominant arm into full abduction ROM.</td>
</tr>
</tbody>
</table>

constructed to perform a series of three MVICs, across a total of four muscle tests (Table 2). The four MVIC positions tested in this study have been previously reported (Table 2). Each contraction lasted for approximately five seconds, with a gradual increase of contraction strength over one second, sustained maximum contraction for three seconds and a gradual release over the final second. To reduce the effects of fatigue, each MVIC trial was performed three times for five seconds, with a three-minute rest between each trial. The highest value from the middle one-second interval of each MVIC trial was recorded for each portion of each muscle.

DATA PROCESSING AND ANALYSIS

For surface and fine wire EMG data processing, a customized software platform in MATLAB (2009a, The Math Works, Inc., Natick, Massachusetts, USA) was employed, following SENIAM standards. For both the fine wire and surface EMG data, direct current offsets were removed. For the surface EMG data, a fourth-order, zero-lag bandpass digital Butterworth filter between 20 and 500 Hz was used. For the fine wire EMG data, a fourth-order, zero-lag bandpass digital Butterworth filter between 20 and 750 Hz was used. Both the surface and fine wire EMG data were then full-wave rectified and then linear enveloped by low-pass filtering with a zero-lag fourth-order Butterworth at 6 Hz. All data were then normalized to each muscle MVIC and expressed as a percentage MVIC (%MVIC). For the analysis of the surface and fine wire EMG outputs, R language (R Core Team, version 3.6, Vienna, Austria) and RStudio (version 1.2.1335, RStudio Team RStudio, Inc., Boston, MA) were used. For each condition (i.e., exercise), the initial and sixth repetition were discarded from analyses, leaving four repetitions for each condition. The peak muscle activation (%MVIC) from each of the four trial was obtained, then averaged for each individual participant, which is consistent with previous methods to obtain a %MVIC. An ensemble
Table 2. Maximal Voluntary Isometric Contraction (MVIC) test procedures.

<table>
<thead>
<tr>
<th>MVIC test</th>
<th>Muscle</th>
<th>Test description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty can test⁹</td>
<td>Supraspinatus</td>
<td>Shoulder abducted to 90° in the scapula plane with internal humeral rotation and the elbow extended. The arm is maximally and isometrically abducted as resistance is applied at the elbow.</td>
</tr>
<tr>
<td>Internal rotation⁹</td>
<td>Subscapularis</td>
<td>Shoulder abducted to 90° in the scapula plane with neutral humeral internal rotation and the elbow flexed to 90°. The arm is maximally and isometrically internally rotated as resistance is applied at the wrist.</td>
</tr>
<tr>
<td>External rotation¹³</td>
<td>Infraspinatus</td>
<td>Shoulder abducted to 0°, neutral humeral internal rotation and the elbow flexed to 90°. The arm is maximally and isometrically externally rotated as resistance is applied at the wrist.</td>
</tr>
<tr>
<td>Abduction</td>
<td>Anterior, middle and posterior deltoid</td>
<td>The shoulder is abducted to 90° with the participant upright. Resistance is applied just above the elbow.</td>
</tr>
</tbody>
</table>

Figure 1. The eight exercises completed during the study, including: (A) Pendulum, (B) Rock the Baby (Circumduction), (C) Rock the Baby (Elevation), (D) Table Slide, (E) Pulley-assisted Elevation, (F) Assisted Wall Slide, (G) Dowel-assisted Forward Elevation, (H) Dowel-assisted External Rotation.

average across all participant’s mean peak muscle activations were then calculated for each muscle and condition.

DATA ANALYSIS

Descriptive statistics are reported and displayed for each individual muscle as mean ± 95% confidence intervals. Maximum EMG expressed in %MVIC values for each muscle were averaged for the participant’s three trials. Muscle activity was categorized as low, 0% to 15% MVIC; low to moderate, 16% to 20% MVIC; moderate, 21% to 40% MVIC; high, 41% to 60% MVIC; and very high, greater than 60% MVIC.⁷ Descriptive statistics and radar plots for each condition were presented.

RESULTS

The mean (± SD) age, height, and weight for the entire group was 28.5 ± 4.6 years, 1.75 ± 0.10 m, and 75.9 ± 13.8 kg, respectively. Table 3 shows mean %MVIC values and 95% confidence intervals for the supraspinatus, infraspinatus, subscapularis, and deltoid muscles according to exercises performed, ranked from least to the most amount of activity generated. Specifically, for the supraspinatus, the standard pendulum, and gravity-minimized exercises, such as the table slide and assisted wall slide, were the only exercises to generate low-levels of activation (i.e., below 15% MVIC). Interestingly, the rock-the-baby exercises recruited the shoulder muscles to a greater extent than that of the standard pendulum exercise; especially the elevation version of the exercise which consistently generated moderate levels of activity.

Figures 2 and 3 present radar plots visualizing comparisons between evaluated muscles in terms of muscle activation expressed as %MVIC during the four PROM (Figure 2) and four AAROM (Figure 3) exercises.

DISCUSSION

The main finding of the current study was that clear differences were observed between active and assistive (PROM and AAROM) exercises for the anterior deltoid and supraspinatus, but not for the infraspinatus or subscapularis. However, a clear distinction between PROM and AAROM exercises could not be identified. Furthermore, the majority of PROM and AAROM exercises (apart from the pendulum exercise, table slide exercise and the supported vertical wall slide) all exceeded the 15% MVIC threshold, which has been suggested as an upper limit of a safe loading range during exercises in the early stages following rotator cuff repair.
As such, many of the exercises evaluated in this study, and their use in the earlier stages of a rehabilitation continuum to regain active motion should be questioned, and moreover, subdividing exercises into categories of PROM and AAROM may not be necessary following rotator cuff repair. Instead, progression of exercises prior to commencing active motion should be based on factors such as patient comfort, pain tolerance, and available ROM.

In the current study, active flexion and abduction for the supraspinatus, anterior deltoid, and middle deltoid elicited high mean %MVICs, compared to all assistive (PROM and AAROM exercises) which generated low, low-to-moderate and moderate %MVICs. For the infraspinatus, active flexion and abduction was only seen to generate a moderate mean %MVIC, clearly not differentiating between assistive exercises which were also found to generate low, low-to-moderate and moderate %MVICs. This finding is similar to that by Gaunt et al, who also observed clear distinctions between assistive exercises (PROM and AAROM) and active exercises for the supraspinatus and anterior deltoid, but not infraspinatus. In the current study, the subscapularis was also found to only generate moderate mean %MVICs, which did not materially differ from more assistive exercises. However, no clear differences were observed between exercises categorized as passive (PROM) or active-assisted (AAROM), which suggests further subdividing assistive exercises into PROM and AAROM exercises based on muscle activity is not necessary to protect the supraspinatus following a rotator cuff repair, nor for scenarios in which deltoid protection is necessary, such as for an open rotator cuff repair.

Table 3. Percent MVIC for passive (PROM) and active-assisted (AAROM) exercises from least to greatest, for each muscle tested.

<table>
<thead>
<tr>
<th>Supraspinatus</th>
<th>Infraspinatus</th>
<th>Subscapularis</th>
<th>Anterior Deltoid</th>
<th>Middle Deltoid</th>
<th>Posterior Deltoid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pendulum, 14 (11 to 18)</td>
<td>Pendulum, 12 (8 to 16)</td>
<td>Dowel-assisted ER, 18 (9 to 27)</td>
<td>Dowel-assisted ER, 3 (2 to 3)</td>
<td>Dowel-assisted ER, 13 (5 to 21)</td>
<td>Dowel-assisted ER, 3 (2 to 3)</td>
</tr>
<tr>
<td>Table slide, 15 (12 to 17)</td>
<td>Rock the baby circumduction, 15 (11 to 19)</td>
<td>Pendulum, 19 (12 to 26)</td>
<td>Table slide, 12 (10 to 14)</td>
<td>Table slide, 14 (9 to 20)</td>
<td>Table slide, 5 (4 to 7)</td>
</tr>
<tr>
<td>Assisted wall slide, 15 (11 to 20)</td>
<td>Table slide, 16 (13 to 20)</td>
<td>Pulley elevation, 23 (18 to 28)</td>
<td>Rock the baby circumduction, 15 (13 to 17)</td>
<td>Pendulum, 16 (12 to 20)</td>
<td>Pendulum 10 (8 to 13)</td>
</tr>
<tr>
<td>Rock the baby circumduction, 17 (14 to 21)</td>
<td>Dowel-assisted elevation, 20 (15 to 24)</td>
<td>Active flexion, 24 (18 to 31)</td>
<td>Pendulum, 17 (14 to 20)</td>
<td>Rock the baby circumduction, 16 (12 to 20)</td>
<td>Rock the baby circumduction, 12 (10 to 14)</td>
</tr>
<tr>
<td>Dowel-assisted elevation, 18 (13 to 23)</td>
<td>Rock the baby elevation, 20 (15 to 24)</td>
<td>Dowel-assisted elevation, 25 (18 to 33)</td>
<td>Pulley elevation, 27 (23 to 21)</td>
<td>Assisted wall slide, 28 (24 to 31)</td>
<td>Assisted wall slide, 16 (12 to 21)</td>
</tr>
<tr>
<td>Dowel-assisted elevation, 20 (15 to 24)</td>
<td>Dowel-assisted ER, 25 (20 to 30)</td>
<td>Rock the baby circumduction, 25 (20 to 30)</td>
<td>Assisted wall slide, 29 (27 to 31)</td>
<td>Pulley elevation, 29 (24 to 35)</td>
<td>Pulley elevation, 17 (13 to 21)</td>
</tr>
<tr>
<td>Pulley elevation, 20 (16 to 25)</td>
<td>Pulley elevation, 25 (19 to 31)</td>
<td>Rock the baby elevation, 26 (17 to 35)</td>
<td>Rock the baby elevation, 30 (26 to 33)</td>
<td>Dowel-assisted elevation, 33 (27 to 29)</td>
<td>Dowel-assisted elevation, 17 (13 to 20)</td>
</tr>
<tr>
<td>Rock the baby elevation, 22 (18 to 27)</td>
<td>Assisted wall slide, 25 (20 to 30)</td>
<td>Table slide, 26 (17 to 34)</td>
<td>Dowel-assisted elevation, 33 (30 to 36)</td>
<td>Rock the baby elevation, 34 (29 to 40)</td>
<td>Rock the baby elevation, 26 (21 to 32)</td>
</tr>
<tr>
<td>Active flexion, 43 (40 to 47)</td>
<td>Active abduction, 25 (19 to 30)</td>
<td>Assisted wall slide, 28 (20 to 35)</td>
<td>Active flexion, 43 (40 to 47)</td>
<td>Active flexion, 42 (37 to 48)</td>
<td>Active flexion, 26 (21 to 30)</td>
</tr>
<tr>
<td>Active abduction, 48 (44 to 52)</td>
<td>Active flexion, 28 (23 to 34)</td>
<td>Active abduction, 33 (24 to 42)</td>
<td>Active abduction, 48 (44 to 52)</td>
<td>Active abduction, 47 (44 to 52)</td>
<td>Active abduction, 35 (29 to 40)</td>
</tr>
</tbody>
</table>

Results are presented as means (95% confidence intervals).

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Figure 2. Radar plots showing muscular activity during the four passive range of motion (PROM) rehabilitation exercises.
Figure 3. Radar plots showing muscular activity during the four active-assisted range of motion (AAROM) rehabilitation exercises.
Electromyographic Evaluation of Early-Stage Shoulder Rehabilitation Exercises Following Rotator Cuff Repair

In the current study, the pendulum exercise was one of two exercises considered "passive" which did not generate >15% MVIC in the supraspinatus. The pendulum is a popular exercise amongst therapists, and commonly employed early in rehabilitation to restore shoulder mobility following rotator cuff repair. Indeed, the pendulum has been the subject of many EMG analyses which have frequently found it to generate low levels of EMG activity.\textsuperscript{17–19} The mean %MVIC of the supraspinatus during pendulum exercises in the current study was 14%, greater than that reported by Gurney et al (12%),\textsuperscript{18} McCann et al (9%),\textsuperscript{19} and Ellsworth et al (10%),\textsuperscript{20} though more similar to the large, correctly performed pendulums in the study by Long et al (15.7%).\textsuperscript{16} In their study, Long et al\textsuperscript{16} found that large, incorrectly performed pendulums generate moderate levels of supraspinatus muscle activity (18.8%). In what is meant to be a PROM exercise on the shoulder generated by trunk motion, patients often perform this as an AROM exercise by using their shoulder muscles to swing the arm rather than simply allowing it to hang in a relaxed state.\textsuperscript{16} Given that pendulum exercises are often prescribed as a home exercise, it is possible that patients may incorrectly perform these without proper instruction and supervision, which may potentially overload a newly repaired rotator cuff.

The rock-the-baby exercise is an alternate version of the standard pendulum exercise performed by having the patient control the operated arm with the non-surgical arm, with the goal of protecting the repair from increased stress that the standard pendulum can cause if performed incorrectly. Without the non-surgical arm guiding and supporting the surgical arm, the weight of the arm is reduced and, theoretically, reduces the demand on the shoulder musculature. Previous research has supported this rationale of unloading the surgical arm during AROM and AAROM exercises.\textsuperscript{21} In the current study, it was interesting to note that the rock-the-baby exercise (when performing circumduction) elicited a low-to-moderate mean %MVIC (17%), and a moderate mean %MVIC (22%) when performing elevation on the supraspinatus. This was higher than the mean %MVIC during pendulum exercise reported in this study, as well as others.\textsuperscript{13,16–18} No previous studies have directly compared this assisted version of the pendulum with the standard pendulum exercise, making comparison to existing literature difficult. However, it is possible that the rock-the-baby produced more muscle activity than standard pendulum exercises were that, despite being unloaded by the contralateral arm, these exercises may have been supported through a larger ROM, generating more muscle activity. This is consistent with the findings by Long et al\textsuperscript{16} who found that pendulums, when performed in a larger diameter, generated significantly higher mean %MVCs. Future research could look to expand on this research by controlling for small and large diameter versions of this exercise.

The table slide was another exercise below the 15% MVIC threshold which could be considered appropriate to be prescribed in early-stage rehabilitation. The primary concentric phase of the table slide, that is the forward motion of the exercise, moves perpendicular to gravity with the weight of the arm supported and removing a large gravitational burden on the shoulder, subsequently reducing the demand on the shoulder musculature.\textsuperscript{21} The mean %MVIC of the supraspinatus during this exercise produced similar MVICs to that reported by Gaunt et al (12%),\textsuperscript{13} yet much higher than those reported in the study by Jung et al (4%).\textsuperscript{22} It is possible these differences are due to how the exercise was performed. In the study by Jung et al,\textsuperscript{22} participants were instructed to generate forward movement by flexing the trunk, with the hand passively sliding until reaching an end range. Conversely, in this present study, forward movement was generated preferentially by the shoulder, similar to that by Gaunt et al,\textsuperscript{13} which may explain the reason for the larger mean %MVCs in the supraspinatus, and also for the infraspinatus and subscapularis. The mean %MVIC of the anterior deltoid and middle deltoid produced similar MVICs to those observed in the study by Cools et al\textsuperscript{23} (11% and 11.9%, respectively).

The supported vertical wall slide was the only AAROM exercise which did not generate over 15% MVIC. The mean %MVIC of the supraspinatus during this exercise produced similar MVICs to those reported by Wise et al (13%)\textsuperscript{21} and Gaunt et al (21%).\textsuperscript{13} This observed low muscle activation is potentially due to unloading and compressive effects of the supporting surface, and possibly due to additional support of the shoulder from the contralateral arm, throughout AROM.\textsuperscript{21} However, this exercise has conflicting clinical evidence regarding its use in early rehabilitation. It has been suggested this exercise, also known as the wall slide or wall walk, is more appropriately used in later stages of rehabilitation once the patient can actively elevate the arm to at least 150° without pain, to build endurance for active elevation rather than as an assist for improving elevation ROM.\textsuperscript{5} Mean %MVCs observed for the anterior and middle deltoid were similar to those observed in the study by Cools et al\textsuperscript{23} (11% and 11.9%, respectively).

Dowels and pulleys are often used by patients to actively assist forward flexion motion so as not to place excessive stress on an early cuff repair. AAROM exercises using a dowel or pulley to elevate the arm were shown to generate over 15% MVIC for muscles of the rotator cuff which is consistent with previous studies, suggesting that their use early in rehabilitation might not be appropriate.\textsuperscript{13,17,18} The mean %MVIC of the supraspinatus when using a pulley to elevate the arm in the current study (20%) was similar to that reported by Gurney et al (18.5%),\textsuperscript{18} Gaunt et al (17%),\textsuperscript{13} and Dockery et al (17.6%),\textsuperscript{17} all classified as low-to-moderate.

No exercises employed in the current study were found to generate low levels of muscular activation in the subscapularis. This is an important consideration for clinicians working with patients undergoing rotator cuff repair involving the subscapularis, or even in shoulder arthroplasty surgery whereby the release and subsequent repair of the subscapularis tendon is involved. In these cases, clinicians should abide by soft-tissue precautions; so as not to jeopardize the newly repaired tissue. The mean %MVCs in the current study were inconsistent when compared with those reported by Gurney et al.\textsuperscript{18} In their study, pulley elevation, pendulums and dowel-assisted elevation generated 7.3%, 9.4% and 9.6% median MVIC, respectively; all falling considerably below the low activity threshold.\textsuperscript{18} Aside from the differences in statistical reporting, the differences observed between the study by Gurney et al,\textsuperscript{18} and the present study are possibly due to variances in testing procedures. In the...
current study, peak amplitudes across four repetitions were averaged over three trials to provide a mean %MVIC value, which differs from the study by Gurney et al., who reported mean EMG activity values for one repetition (or 10 seconds in the case of pendulums) of a task.

LIMITATIONS

Firstly, this study evaluated participants with healthy functioning shoulders in order to obtain an accurate maximal voluntary contraction for comparison. As a result, the activity of the shoulder muscles in healthy participants may not be representative of the activity of individuals with a pathological or post-surgical shoulder. Previous authors have suggested that patients with painful, symptomatic shoulders activate muscles differently and are unable to remain as passive as healthy control subjects. Therefore, caution should be applied in extrapolating data collected from healthy subjects and applying results to clinical populations. We did have concerns about undertaking such a study in an early post-operative cuff cohort, given the risk of introducing infection and seeking more insight into the specific loading capabilities of each exercise initially.

Secondly, the mean age of the participants in our cohort is younger than the typical patient undergoing rotator cuff surgery. However, the current study sought to initially recruit a cohort with a lower risk of asymptomatic shoulder pathology. Furthermore, many of the participants in the current study were either physiotherapists or exercise physiologists and, therefore, were familiar with most of the rehabilitation tasks which also served to ensure the exercises were performed correctly.

Finally, repair site tension can only be estimated, as EMG is not a direct measurement of the potential damaging force incurred at the site of repair. As a result, EMG studies cannot provide definitive guidelines on “safe” versus “unsafe” exercises applicable to all patients without assumptions regarding the force-EMG relationships, as well as the force levels that will cause damage (or failure) to a repair. Muscle activity level, along with the plane of motion, cyclic loading and the weight and length of an individual’s upper limb, are also likely to affect the tension on the repaired tissue. While only moderate correlations have been made between muscle tension and EMG activity, in the clinical setting, where stress and tension imparted by rehabilitation exercises cannot be measured, EMG evidence does offer a pragmatic method to base the progression of therapeutic exercises on likely stress on the repaired rotator cuff.

CONCLUSION

The results of the current study indicate that commonly performed PROM and AAROM exercises, with the exception of the pendulum exercise, table slide exercise and the assisted wall slide, all exceeded the 15% MVIC threshold of the supraspinatus. Fifteen percent or below (defined as low activity) has been suggested as an upper limit of a safe loading range during exercises in the early stages following rotator cuff repair. A clear distinction between PROM and AAROM exercises could only be identified for the anterior deltoid, and not for the supraspinatus, which suggests that subdividing PROM and AAROM forward flexion exercises based on muscle activity is not necessary to protect the supraspinatus following rotator cuff repair. The current study, which was undertaken in normal, asymptomatic shoulders, would suggest that the early progression of exercises prior to commencing active motion after rotator cuff repair may be better based on factors such as patient comfort, pain tolerance and available ROM.

ETHICS APPROVAL

Ethics approval was obtained by the University of Western Australia Human Research Ethics Office (RA/4/1/7559).

CONFLICT OF INTEREST STATEMENT

No other authors have any conflicts of interest.

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Original Research

Cumulative Effects of a Week’s Training Loads on Shoulder Physical Qualities and Wellness in Competitive Swimmers

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Keywords: training, overtraining, musculoskeletal, fatigue

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**Background**

Competitive swimmers are exposed to high training loads, which can contribute to the development of shoulder pain. There is a lack of research investigating the interactions between the accumulation of training loads and factors associated to shoulder pain in swimmers.

**Purpose**

The primary objective was to analyze the changes in shoulder physical qualities and wellness factors over a week of training in competitive swimmers. A secondary objective was to compare the changes in these variables between different swim-training volumes performed during the week.

**Design**

Cross-sectional.

**Methods**

Thirty-one national and regional-level swimmers were included (18 females, 13 males; age= 15.5 ± 2.2 years). Active shoulder external rotation (ER) range of motion (ROM), shoulder-rotation isometric torque, and wellness factors using the Hooper questionnaire were measured twice over the week: a baseline measurement (before Monday’s training session) and a follow-up during the week. Participants were divided into a high-volume group (HVG) and low-volume group (LVG) based on the day follow-up was performed. HVL (n= 15) was tested at the end of the training week (after Saturday’s session) and LVG (n= 16) during the week (after Thursday or Friday’s session). Rating of perceived exertion (RPE) of the whole week was recorded after the follow-up session.

**Results**

At follow-up, the LVG averaged a volume of 26.2 ± 2.2 km, whereas the HVG averaged a volume of 37.5 ± 3.7 km. LVG and HVG participants decreased active shoulder ER ROM on dominant (p= 0.002; p= 0.006) and nondominant sides (p= 0.001; p= 0.004), displayed increased muscular soreness (p< 0.001; p= 0.007) and worsened overall wellness (p< 0.001; p= 0.010). Fatigue (p= 0.008) and poor sleep quality were increased (p= 0.023) in HVG, but not in LVG. There were no changes in shoulder-rotation torque and stress in any group. Regarding between-groups differences, only weekly RPE was higher (p= 0.004) in HVG.

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Conclusions

The accumulation of training loads over the week negatively affect physical and wellness factors. Greater swim-volumes were associated with an increase perception of training loads. The regular monitoring of multiple factors to assess swimmers’ response to training might be necessary.

Level of evidence

INTRODUCTION

The etiology of injuries in sports is multifactorial including the dynamic interaction among biomechanical, psychological, behavioral, and training-related factors. Competitive swimmers are exposed to large training loads, swimming up to 14,000 m/day. Given that 90% of the forceful power comes from the upper limbs, the shoulder is the most commonly injured body part. With a prevalence as high as 91%, shoulder pain is the main reason for missed training in competitive swimmers. Injuries in this population occur mainly from repetitive strain and microtrauma as a result of high training intensity or volume. A systematic review supported this, reporting moderate associations between training volume and shoulder pain in adolescent competitive swimmers. Considering the dynamic and multifactorial nature of sports injuries and the importance of training loads on the development of shoulder pain in swimmers, it is necessary to understand the interaction between training loads and other risk factors.

Stresses induced by training loads in swimmers have been shown to have a negative effect on shoulder physical qualities. Researchers have reported immediate decreases of shoulder external rotation (ER) range of movement (ROM), pectoralis minor length, and isometric rotation torque after a single swim session. These physical qualities have been reported as potential risk factors for shoulder pain in swimmers, their acute maladaptation can potentially increase the predisposition to shoulder injury. The intensity of the training session has been shown to be an important component of training loads leading to some of these changes. To date, there is evidence that a single swim-practice can lead to acute shoulder maladaptations, however, it is unknown whether these maladaptations are affected by the accumulation of multiple sessions. Also, training intensity is the only component of training loads that has been investigated; no studies have examined the effect of swim-training volume on physical qualities of the shoulder.

General wellness in swimmers is also affected by training loads. The peak swim-training volume during a season has been associated with mood and sleep disturbances. It has been also shown that acute increases in swim-training volume negatively affect muscular soreness, mood, perception of training loads, and psychological well-being. Importantly, impairments of wellness factors have been found in overtrained swimmers. Although wellness factors have not been directly associated with shoulder pain in swimmers, they have been reported as injury predictors in other sports. There is evidence of a dose-response relationship between training loads and wellness in swimmers, the peak swim-volume during a season and acute increases in swim-volume negatively affect wellness factors. However, it is unknown how they are affected by different swim-training volumes performed over the course of a week.

There is a lack of information about the interaction between training loads and risk factors for shoulder pain in swimmers. Importantly, no studies have simultaneously monitored shoulder physical qualities and self-reported wellness factors such as fatigue, muscular soreness, sleep quality, and stress in this population. Given the dynamic and multifactorial nature of injuries in sports and the role of training loads, it is important to understand how the accumulation of training loads affect factors associated to shoulder pain in swimmers and how different swim-training volumes influence these changes. This might help coaches and practitioners to discern which factors and when they need to be monitored. Monitoring can help to understand a swimmer’s response to training to adequately prescribe and manage training loads, minimizing the risk of injury and maximizing performance. The primary objective was to analyze the changes in shoulder physical qualities and wellness factors over a week of training in competitive swimmers. A secondary objective was to compare the changes in these variables between different swim-training volumes performed during the week.

MATERIALS AND METHODS

EXPERIMENTAL APPROACH TO THE PROBLEM

A cross-sectional study was conducted to assess the impact of a week’s training loads on shoulder physical qualities and wellness factors and to determine the impact of different training volumes on these factors. For the first objective, participants were measured twice over a week: a baseline measurement at the beginning of the week (before Monday’s training session) and a follow-up during the week. For the second objective, participants were divided by convenience sampling into a high-volume group (HVG) and low-volume group (LVG) according to the day the follow-up measurement was performed. The HVG group was measured after Saturday’s training session. This implied that this group was tested after completing all the sessions of the week and thus performed the total weekly swim-volume. Conversely, the LVG was measured during the week (after the Thursday or Friday session). This indicated that, at the time of follow-up, this group had performed less than the total weekly swim-volume.

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PROCEDURES
Baseline measurements included general demographic information, such as sex, age, limb dominance, height, mass, forearm length, and history of shoulder pain. Considering the high number of swimmers that do not discontinue training due to shoulder pain,20 history of shoulder pain was recorded as the presence of significant interfering pain that caused the swimmer to miss or modify training or competition within the previous 12 months. Before testing, participants performed a standardized warm-up consisting of shoulder movements (10 repetitions of ER and IR [0° shoulder abduction] with a yellow TheraBand [The Hygenic Corporation, Akron, OH]). After the warm-up, participants were asked about their readiness to train and completed a wellness questionnaire. Readiness to train was measured separately by asking "Do you feel ready to train at 100% this week?" on a seven-point Likert ranging from 1 (strongly agree) to 7 (strongly disagree). Wellness was obtained with the Hooper questionnaire which includes self-report ratings of muscular soreness, fatigue, sleep quality, and stress using a Likert scale ranging from 1 to 7.16 Then, active shoulder external rotation ROM and shoulder rotation isometric peak torque were measured, assessing the dominant side first. Three trials of each test were performed on both limbs, and the results were averaged for further analysis. For the follow-up session, participants were tested on different days according to the swim-volume group (low-volume or high-volume). Immediately after completion of the training, swimmers exited the pool and repeated baseline testing. Additionally, RPE of the whole week was recorded after the follow-up session.

TRAINING LOADS MONITORING
According to a consensus statement in training loads,21 a combination of external (amount of work performed by the athlete) and internal (athlete's physical and psychological response to external loads) training loads should be used to monitor an athlete's response to training. External training loads were measured by the swim-training volume performed during the testing week. For internal training loads monitoring, it has been recommended to include objective and subjective measures.22 Objective measures included shoulder physical qualities, whereas subjective measures included self-reported wellness factors and weekly RPE.

SWIM TRAINING VOLUME
Swim-training volume was defined as "the average distance or average time swum per week."6 The swim-volume for each swimmer was reported by the coaches at the end of each week and was based on the distance covered at the time of the follow-up measurement. If a participant missed a training session, the volume of the missed session was deducted from the total weekly volume.

PHYSICAL QUALITIES
Regarding shoulder-rotation ROM, only ER was measured. The reason for this was because previous authors7-9 have found changes in ER ROM, but not in IR after a swim training. Shoulder ER ROM was measured using the 'Goniometer Pro' (SufS Co, Bloomfield, NJ) digital inclinometer application for the iPhone (Apple, Inc, Cupertino, CA), which is valid compared to the universal goniometer.23 Participants were positioned in supine with 90° of shoulder abduction and instructed to actively rotate the limb back until reached end available range. A towel roll was placed under the humerus to ensure a correct alignment in the frontal plane.24 This was based on visual inspection, making sure that the humerus was levelled to the acromion process.24 The end range was determined by the available range without any stabilization.

Shoulder rotation isometric peak torque was assessed using a hand-held dynamometer (HHD) (Hoggan MicroFET2; Scientific LLC, Salt Lake City, UT), which has been shown to be reliable and valid compared to the gold standard isokinetic dynamometry.25 Participants were positioned in supine with 90° of shoulder abduction. Before testing, one submaximal trial was performed to ensure correct technique. The HHD was placed on the palmar surface of the forearm for internal rotation and on the dorsal aspect of the forearm for external rotation, proximal to the radioulnar joint crease. Then, participants were instructed to push against the HHD as hard as possible for three seconds, with a resting period of 10 seconds. Force was converted into torque (in newton meters) by multiplying the force (in newtons) by the lever arm length (meters). Torque was normalized to body mass (Nm/kg) and expressed as the percentage of change between the baseline and follow-up measurements. Lever arm length was measured from the olecranon process to the proximal aspect of the styloid process of the ulna.26 To assess muscle balance, the ratio between exter-

PARTICIPANTS
Thirty-four national and regional level swimmers from the same club were recruited to participate in the study. According to a priori power analysis (version 3.1.9.2; G*Power, Heinrich-Heine-Universität, Düsseldorf, Germany), using the t-tests for means (two independent groups), a sample size of 32 participants (16 per group) would be required to detect a large effect size (0.90) with a power of 0.80 and an α level of 0.05. Three participants were unable to complete the follow-up testing; one developed shoulder pain during the testing week, whereas two missed the session due to other reasons. Thirty-one participants were included in final analysis (18 females and 13 males; age = 15.5 ± 2.2 years, range 12-21 years). All swimmers trained year-round and completed a similar number of practices regularly, regardless of the age and level of competition. The participants performed an average training volume of 35,600 ± 4,000 meters per week and average swim sessions of 8.5 ± 0.5 per week. The exclusion criteria included a history of shoulder surgery, shoulder pain at the time of the study, and any pain within the previous 12 months. Before testing, participants were asked about their readiness to train and completed a wellness questionnaire. Readiness to train was measured according to a priori power analysis (version 3.1.9.2; G*Power, University's ethics board and conducted in accordance with the Declaration of Helsinki (Ref.no.HSR1718-100).
nal and internal rotator torque was calculated (ER: IR ratio). Three trials of shoulder ER ROM and rotation peak torque were performed on both limbs, and the results were averaged for further analysis.

Intrarater test-retest reliability for active shoulder ER ROM and rotation isometric torque was established before in a pilot study. Three trials of each measurement were performed on two sessions separated by seven days. The intraclass correlation coefficient, standard error of measurement (SEM), and minimal detectable change (MDC) with 95% of confidence interval for each test were calculated. These results provided information to enable us to determine whether the changes in the shoulder physical qualities were real or due to measurement error (Table 1).

SELF-REPORTED WELLBEING

Common valid instruments to assess athlete’s wellbeing status include The Stress-Recovery Questionnaire for Athletes, The Profile of Mood States, and The Multicomponent Training Distress Scale. Unfortunately, these questionnaires are long and time-consuming, which limits their implementation in the sport setting. Because of this, several authors have incorporated elements of these questionnaires into short, customized, and easy-to-use self-reported measures. Within these studies, a specific set of questions (Hooper questionnaire) have been used in several sports which includes self-report ratings of muscular soreness, fatigue, sleep quality, and stress using a Likert scale ranging from 1 to 7 for rating. Importantly, the Hooper questionnaire has been shown to provide an efficient method of monitoring both overtraining and recovery in swimmers and to have moderate to large relationship with acute load in other sports. Using this questionnaire, each swimmer recorded their current status of muscular soreness (1 = free full movement, 2 = free movement, 3 = fairly free movement, 4 = neutral, 5 = fairly sore, 6 = sore, and 7 = very sore), fatigue (1 = very fresh, 2 = fresh, 3 = fairly fresh, 4 = neutral, 5 = fairly tired, 6 = tired, and 7 = very tired), sleep quality (1 = very restful, 2 = restful, 3 = fairly restful, 4 = neutral, 5 = fairly restless, 6 = restless, and 7 = very restless), and stress (1 = very relaxed, 2 = relaxed, 3 = fairly relaxed, 4 = neutral, 5 = fairly stressed, 6 = stressed, and 7 = very stressed). The individual scores of each item were summed to provide a score of overall perceived wellness.

WEEKLY RPE

The perception of training loads was quantified by the RPE based on the modified version of the category-ratio scale of Borg. Immediately after completing the follow-up session, the swimmers were asked, “On average how hard was your training week?”, on a scale from 0 (rest) to 10 (maximal effort). Researchers have recommended that RPE should be monitored daily. However, as a result of the various training locations of each athlete, the daily measurement of the RPE was not possible. It has been shown that the RPE reported at the end of the week (weekly RPE) has a strong correlation with the RPE reported daily after 24 hours of training (0.87 [CI, 0.78 – 0.93]). Therefore, RPE of the whole week was recorded.

STATISTICAL ANALYSIS

For statistical analysis, SPSS (version 25 for Windows; Inc, Chicago, IL) was used. Demographic data was initially screened for between-group differences using independent sample t-tests for normally distributed data and Mann Whitney test for non-normally distributed data. As all out-

Table 1. One-Week Test-Retest Reliability for Outcome Measures Calculated from the Pilot Study (N = 10)

<table>
<thead>
<tr>
<th>Test</th>
<th>Side</th>
<th>Intraclass Correlation Coefficient (3,3) (95% CI)</th>
<th>Standard Error of Measurementb (%)</th>
<th>Standard Error of Measurementd (%)</th>
<th>Minimal Detectable Changec (%)</th>
<th>Minimal Detectable Changed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External rotation range of motion, a</td>
<td>Dominant</td>
<td>0.958 (0.815-0.991)</td>
<td>2.22</td>
<td>2.1</td>
<td>6.17</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>Nondominant</td>
<td>0.947 (0.783-0.988)</td>
<td>3.81</td>
<td>3.7</td>
<td>10.57</td>
<td>10.3</td>
</tr>
<tr>
<td>External rotation torque, Nm/kg</td>
<td>Dominant</td>
<td>0.984 (0.928-0.996)</td>
<td>0.02</td>
<td>4.8</td>
<td>0.05</td>
<td>13.4</td>
</tr>
<tr>
<td></td>
<td>Nondominant</td>
<td>0.988 (0.950-0.997)</td>
<td>0.02</td>
<td>4.9</td>
<td>0.05</td>
<td>13.5</td>
</tr>
<tr>
<td>Internal rotation torque, Nm/kg</td>
<td>Dominant</td>
<td>0.982 (0.913-0.996)</td>
<td>0.02</td>
<td>5.2</td>
<td>0.06</td>
<td>14.3</td>
</tr>
<tr>
<td></td>
<td>Nondominant</td>
<td>0.991 (0.959-0.998)</td>
<td>0.02</td>
<td>4.0</td>
<td>0.04</td>
<td>11.0</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval.

a Two-way mixed model. A coefficient ≥ 0.90 is considered excellent reliability, <0.89 to ≥ 0.80, good, ≤0.79 to ≥ 0.70, moderate, and < 0.70, low.
b Standard deviation x √1 – intraclass correlation coefficient.
c Calculated as standard error of measurement x 1.96 x √2.
d Standard error of measurement and minimal detectable change % were calculated by dividing their respective value with the average of the test and retest values.
Table 2. Descriptive and baseline characteristics of participants (N = 31)

<table>
<thead>
<tr>
<th></th>
<th>Low-Volume Group (n = 16)</th>
<th>High-Volume Group (n = 15)</th>
<th>Between Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Range (min-max)</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Swim-volume at follow-up, km</td>
<td>26.2 ± 2.2</td>
<td>5.0 (25.0 - 30.0)</td>
<td>37.5 ± 3.7</td>
</tr>
<tr>
<td>Training hours at follow-up, h</td>
<td>12.0 ± 0.6</td>
<td>2.5 (10.9 - 13.4)</td>
<td>15.3 ± 0.7</td>
</tr>
<tr>
<td>Age, y</td>
<td>15.1 ± 2.2</td>
<td>7.0 (12.0 - 19.0)</td>
<td>15.9 ± 2.2</td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>54.8 ± 9.6</td>
<td>29.0 (40.0 - 69.0)</td>
<td>62.8 ± 9.2</td>
</tr>
<tr>
<td>Height, cm</td>
<td>166.6 ± 10.2</td>
<td>320.0 (150.0 - 182.0)</td>
<td>170.5 ± 10.4</td>
</tr>
<tr>
<td>Readiness to train, scale 1-7</td>
<td>2.1 ± 0.9</td>
<td>3.0 (1.0 - 4.0)</td>
<td>2.0 ± 0.9</td>
</tr>
<tr>
<td>Sex, male: female</td>
<td>5: 11</td>
<td></td>
<td>8: 7</td>
</tr>
<tr>
<td>Level of competition</td>
<td>8 national, 8 regional</td>
<td></td>
<td>11 national, 4 regional</td>
</tr>
<tr>
<td>History of shoulder pain, yes: no</td>
<td>6:10</td>
<td></td>
<td>4:11</td>
</tr>
</tbody>
</table>

SD, standard deviation.
* Difference between groups (p < 0.05).

Some measures showed normal distribution, results are expressed as means and standard deviation (SD). Paired t-test was used to assess within-group differences between pre- and post-measurements and independent sample t tests were used to assess between-group differences. The Cohen d effect size (ES) was calculated to determine the magnitude of any difference among measurements: >0.8 (large), 0.5-0.79 (medium), 0.49-0.20 (small), and <0.2 (trivial). Differences were considered as significant when p values were ≤ 0.05. Additionally, a swim-volume threshold was calculated to determine the percentage of swimmers above or below a specific swim-volume in each group. In the LVG, two SD were added to the average value of the swim-volume obtained, whereas, in the HVG, two SD were subtracted from the average of the swim-volume. This is an operational value that will determine a swim-volume threshold where 95% of the participants in each group lie.

RESULTS

Table 2 presents the baseline characteristics of the participants. The HVG reported greater swim-volume (p < 0.001) and training hours (p < 0.001) at follow-up. The LVG averaged a volume of 26.2 ± 2.2 km, whereas the HVG averaged a volume of 37.5 ± 3.7 km. The swim-volume threshold was set at 30 km, identifying that 95% of swimmers in the HVG performed more than 30 km (37.5 - 2 SD [3.7]) and 95% of swimmers in the LVG performed less than 30 km (26.2 + 2 SD [2.2]) at follow-up.

For shoulder ER ROM, the LVG demonstrated decreases with large ES for the dominant (p = 0.002; d = 1.22) and nondominant sides (p = 0.001; d = 0.82). The HVG demonstrated decreases with large ES for the dominant (p = 0.006; d = 0.99) and nondominant sides (p = 0.004; d = 1.25) (Table 3, Figure 1). In both groups, the average change on the dominant side exceeded the MDC, whereas it only exceeded the SEM on the nondominant side. There was no significant difference between groups. For isometric peak torque, there was no significant pre-post and between-group difference in external rotator, internal rotator, or ER: IR ratio (Table 3).
Figure 1. Box plots showing the change in ER ROM for low and high-volume groups, on the dominant and nondominant shoulder.

The lower and upper edge of the box indicates the 25th and 75th percentile of the sample respectively. The height of the box indicates the interquartile range, and the line inside the box shows the median. The X inside the box represents the mean. The whiskers represent extreme data points that are no more than 1.5 times the interquartile range from the lower and upper edges of the box. The circles beyond the whiskers represent outliers. Abbreviations: ROM, range of motion; ER, external rotation; °, angle.
<table>
<thead>
<tr>
<th>Test</th>
<th>Side</th>
<th>Low-volume group n = 16</th>
<th></th>
<th>Mean Difference</th>
<th>% Change</th>
<th>Effect Size</th>
<th>p Value</th>
<th></th>
<th>Mean ± SD</th>
<th>% Change</th>
<th>Effect Size</th>
<th>p Value</th>
<th>Between group p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>External rotation ROM, °</td>
<td>D</td>
<td>99.0 ± 5.7</td>
<td>86.8 ± 14.3</td>
<td>-12.2</td>
<td>-16.5 ± 18.0</td>
<td>1.22</td>
<td>0.002*</td>
<td>98.3 ± 7.9</td>
<td>89.9 ± 8.9</td>
<td>-8.4</td>
<td>-10.2 ± 13.2</td>
<td>0.99</td>
<td>0.006*</td>
</tr>
<tr>
<td></td>
<td>ND</td>
<td>93.3 ± 9.4</td>
<td>84.7 ± 11.5</td>
<td>-8.6</td>
<td>-11.1 ± 11.3</td>
<td>0.82</td>
<td>0.001*</td>
<td>99.9 ± 6.8</td>
<td>91.3 ± 6.9</td>
<td>-8.6</td>
<td>-10.0 ± 11.8</td>
<td>1.25</td>
<td>0.004*</td>
</tr>
<tr>
<td>Internal rotator torque, Nm/kg</td>
<td>D</td>
<td>0.53 ± 0.13</td>
<td>0.58 ± 0.18</td>
<td>+0.05</td>
<td>+5.0 ± 19.9</td>
<td>0.31</td>
<td>0.12</td>
<td>0.50 ± 0.12</td>
<td>0.51 ± 0.12</td>
<td>+0.01</td>
<td>+1.2 ± 18.8</td>
<td>0.08</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>ND</td>
<td>0.51 ± 0.17</td>
<td>0.56 ± 0.17</td>
<td>+0.05</td>
<td>+9.0 ± 17.5</td>
<td>0.29</td>
<td>0.058</td>
<td>0.51 ± 0.12</td>
<td>0.50 ± 0.10</td>
<td>-0.01</td>
<td>-1.0 ± 11.7</td>
<td>0.09</td>
<td>0.78</td>
</tr>
<tr>
<td>External rotator torque, Nm/kg</td>
<td>D</td>
<td>0.48 ± 0.12</td>
<td>0.47 ± 0.11</td>
<td>-0.01</td>
<td>-0.8 ± 12.6</td>
<td>0.08</td>
<td>0.94</td>
<td>0.45 ± 0.08</td>
<td>0.43 ± 0.07</td>
<td>-0.02</td>
<td>-5.2 ± 16.1</td>
<td>0.25</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>ND</td>
<td>0.40 ± 0.12</td>
<td>0.43 ± 0.14</td>
<td>+0.03</td>
<td>+6.9 ± 14.5</td>
<td>0.23</td>
<td>0.067</td>
<td>0.40 ± 0.08</td>
<td>0.41 ± 0.08</td>
<td>+0.01</td>
<td>+1.8 ± 15.2</td>
<td>0.12</td>
<td>0.54</td>
</tr>
<tr>
<td>ER:IR ratio</td>
<td>D</td>
<td>0.89 ± 0.08</td>
<td>0.84 ± 0.14</td>
<td>-0.05</td>
<td>-9.4 ± 19.8</td>
<td>0.43</td>
<td>0.18</td>
<td>0.92 ± 0.11</td>
<td>0.87 ± 0.19</td>
<td>-0.05</td>
<td>-8.8 ± 22.3</td>
<td>0.33</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>ND</td>
<td>0.81 ± 0.20</td>
<td>0.77 ± 0.12</td>
<td>-0.04</td>
<td>-5.4 ± 26.7</td>
<td>0.27</td>
<td>0.48</td>
<td>0.79 ± 0.13</td>
<td>0.81 ± 0.12</td>
<td>+0.02</td>
<td>2.3 ± 11.8</td>
<td>0.15</td>
<td>0.40</td>
</tr>
</tbody>
</table>

D, dominant; ND, nondominant; SD, standard deviation.
* Difference (p < 0.01).
Regarding wellness factors (Table 4, Figure 2), self-reported muscular soreness increased \((p = 0.001; \ d = 0.81)\) and overall wellness worsened with large ES \((p < 0.001; \ d = 1.33)\) in the LVG. There was no difference between testing sessions for sleep quality, fatigue, or stress. In the HVG, both muscular soreness \((p = 0.007; \ d = 0.63)\) and poor sleep quality increased with moderate ES \((p = 0.023; \ d = 0.69)\). Fatigue increased \((p = 0.008; \ d = 0.96)\) and overall wellness worsened \((p = 0.010; \ d = 0.80)\) with a large ES. No difference was reported in stress. There was no difference for muscular soreness, sleep quality, fatigue, stress, and overall score between groups.

Weekly RPE differed significantly between groups with large effect size \((p = 0.004; \ d = 1.15)\) (Figure 2). The HVG reported higher weekly RPE scores (mean = 7.13 points, SD = 1.3; range = 5-9) than the LVG (mean = 5.63 points, SD = 1.3; range = 3-7).
Table 4. Mean results for within-group and between-group comparison for wellness factors (N = 31)

<table>
<thead>
<tr>
<th>Test</th>
<th>Low-volume group (n = 16) Mean ± SD</th>
<th>Follow-up Mean ± SD</th>
<th>% Change</th>
<th>Effect Size</th>
<th>p Value</th>
<th>High-volume group (n = 15) Mean ± SD</th>
<th>Follow-up Mean ± SD</th>
<th>% Change</th>
<th>Effect Size</th>
<th>p Value</th>
<th>Between group p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial Session Mean ± SD</td>
<td>Mean Difference</td>
<td></td>
<td></td>
<td></td>
<td>Initial Session Mean ± SD</td>
<td>Mean Difference</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscular soreness</td>
<td>2.75 ± 1.1</td>
<td>4.25 ± 1.1</td>
<td>+1.50</td>
<td>32.5 ± 27.9</td>
<td>1.33</td>
<td>3.00 ± 1.4</td>
<td>3.87 ± 1.3</td>
<td>+0.87</td>
<td>22.7 ± 28.6</td>
<td>0.63</td>
<td>0.007*</td>
</tr>
<tr>
<td>Sleep quality</td>
<td>3.25 ± 1.6</td>
<td>3.69 ± 1.0</td>
<td>+0.44</td>
<td>12.6 ± 36.3</td>
<td>0.33</td>
<td>2.53 ± 0.8</td>
<td>3.13 ± 0.9</td>
<td>+0.60</td>
<td>15.2 ± 27.7</td>
<td>0.69</td>
<td>0.023*</td>
</tr>
<tr>
<td>Fatigue</td>
<td>3.38 ± 1.2</td>
<td>4.06 ± 1.1</td>
<td>+0.68</td>
<td>13.0 ± 34.5</td>
<td>0.60</td>
<td>3.00 ± 1.0</td>
<td>4.27 ± 1.6</td>
<td>+1.27</td>
<td>21.7 ± 33.3</td>
<td>0.96</td>
<td>0.008*</td>
</tr>
<tr>
<td>Stress</td>
<td>2.69 ± 1.1</td>
<td>3.13 ± 1.0</td>
<td>+0.53</td>
<td>8.9 ± 38.2</td>
<td>0.43</td>
<td>2.47 ± 1.0</td>
<td>2.60 ± 1.2</td>
<td>+0.13</td>
<td>2.8 ± 39.9</td>
<td>0.12</td>
<td>0.63</td>
</tr>
<tr>
<td>Overall wellness</td>
<td>12.3 ± 4.3</td>
<td>15.3 ± 3.0</td>
<td>+3.00</td>
<td>22.0 ± 17.4</td>
<td>0.81</td>
<td>11.0 ± 3.4</td>
<td>13.9 ± 3.8</td>
<td>+2.90</td>
<td>19.8 ± 23.7</td>
<td>0.80</td>
<td>0.010*</td>
</tr>
</tbody>
</table>

* Difference (p < 0.05).

The individual scores of each item were summed to provide a total score of overall perceived wellness.
DISCUSSION

The aims of this study were to analyze the changes in shoulder physical qualities and wellness factors over a week of training in competitive swimmers and compare the changes in these variables between different swim-training volumes performed. For the first objective, shoulder ER ROM and self-reported muscular soreness, sleep quality, fatigue, and overall wellness were negatively affected over a week's training, but isometric peak torque and self-reported stress were not. Within-group analysis showed that both groups reported decreases in shoulder ER ROM and increases in self-reported muscular soreness; however, only the HVG reported impairments in fatigue and sleep quality at follow-up. For the second objective, the HVG reported higher weekly RPE scores compared to the LVG at follow-up. However, there were no significant differences in shoulder physical qualities and wellness factors between groups. Our results show that the accumulation of training loads over a week negatively affect physical and wellness factors in swimmers. Also, higher swim-volumes were mainly associated with an increased perception of training loads.

WEEKLY RPE

The weekly RPE was significantly higher in the HVG than the LVG with large ES (d = 1.15). The LVG perceived the training week as "hard" (RPE mean = 5.63 points), whereas the HVG perceived the training week as "really hard" (RPE mean = 7.13 points). This indicates that as the swim-training volume increases towards the end of the week, training loads are perceived as harder. O'Connor et al. found increases in RPE values after an increase of training volume over three days in competitive swimmers. Interestingly, these changes were associated with increases in self-reported fatigue, muscular soreness, and mood. Although this study showed changes in most of the wellness and physical factors during the week, there were no significant differences between groups. This indicates that higher swim-volumes performed during the week (over 30 km) have no additional impact on these factors. These findings might suggest that these factors are more affected by the changes in swim-volume rather than the total volume performed.

SHOULDER PHYSICAL QUALITIES

To the authors knowledge, this is the first study investigating cumulative effects of training loads on shoulder ER ROM and rotation isometric torque over a training week in swimmers. Both groups reported reductions in ER ROM with large ES. The LVG reported a mean decrease of 12.2° on the dominant and 8.6° on the nondominant side, while the HVG reported a mean decrease of 8.6° on the dominant and 8.4° on the nondominant side. However, the difference between groups was not significant. The results showed that ER ROM is negatively affected by the accumulation of training loads but higher swim-training volumes provide no additional impact. The large ES and values exceeding the MDC in the dominant side for both groups support the clinical meaningfulness of the observed ER ROM changes. Therefore, there is a 95% of confidence that the changes in ER ROM in the dominant side during a training week are attributed to the swim training and not due to measurement error. Although the ES for the nondominant side was large, the values of change only exceeded the SEM, which weakens its clinical significance.

Prior studies in swimmers have only investigated the impact of a single training session on shoulder ER ROM. Matthews et al. found decreases of 5.29° on the dominant side and 3.18° on the nondominant side after a fatigue protocol consisting of eight sets of 100m swim in national level swimmers. Higson et al. reported decreases in ER ROM of 3.4° after a two-hour training session in elite swimmers. More recently, Yoma et al. found decreases in ER ROM of 7.8° on the dominant side and 6.5° on the nondominant side after a high-intensity session of 3.0 km in regional and national level swimmers. The greater changes found in this study may be explained by the cumulative effects of swim-volume over multiple training sessions. In our study, all participants performed between seven and nine sessions and completed a total swim-volume over 25 km, which is a significantly higher volume than in the studies of Matthews et al. (800 m) and Yoma et al. (3.0 km). Probably, the acute reductions of ER ROM after a single session are not completely recovered before the following training, which might explain the greater changes found in this study. Deficits in shoulder ER ROM is a risk factor for shoulder pain in competitive swimmers, therefore, the regular monitoring of shoulder ER ROM might be important to reduce the susceptibility of shoulder injuries due to the accumulation of training loads. Limitations of ER ROM might be important, as this movement is necessary during the mid-recovery phase when the arm is abducted at 90°. Hypothetically, limited ER ROM may increase the probability of mechanical shoulder impingement during the recovery phase.

Contrary to what was expected, the accumulation of training loads over the week did not affect shoulder IR or ER peak torque in any group. In a recent study, investigators found that shoulder rotation isometric peak torque was immediately reduced after a high-intensity session but not after a low-intensity session in competitive swimmers. As part of the regular week, swimmers usually perform a combination of high and low-intensity sessions. The absence of changes in this study might be explained by the possible recovery of force between sessions. Another explanation is that only the maximal peak force was assessed, which may not reflect the demands of swimming. Swimming is an endurance sport that does not reach peak levels of force; thus, it is possible that testing as a proxy measure of muscle endurance rather than maximal force could have given different results. Considering this and the previous studies' results, it can be suggested that changes in rotation force are possibly more affected by the intensity of a single session than the accumulation of swim-volume. Despite this, regular monitoring of shoulder rotation strength in swimmers might be important in clinical practice.

WELLNESS FACTORS

All wellness factors were affected by training performed during the week, except for general stress. Self-reported
Cumulative Effects of a Week’s Training Loads on Shoulder Physical Qualities and Wellness in Competitive Swimmers

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muscular soreness was increased in both groups with moderate to large ES. Various authors have reported increases in self-reported muscular soreness after acute increases of swim-volume during three and ten days of training. Furthermore, Hooper et al. found increases in muscular soreness during the peak volume period of a season in competitive swimmers. Although this study did not assess the impact of acute increases of swim-volume or the effects of a specific period of the season, it was found that the accumulation of training loads over a regular training week also increases the perception of muscular soreness. However, the different swim-volumes performed did not influence the perception of muscular soreness. Laux et al. found an association between the feeling of stiff muscles and feeling vulnerable to injuries in professional football players. The stress-injury model proposes that generalized muscle tension is an important mediating factor between psychological stress and injury; an elevated stress response increases muscle tension narrowing the visual field and increasing distractibility and consequently the risk of injury.

Perceived fatigue and sleep quality were significantly affected in the HVG (moderate to large ES), but not in the LVG. These results might be explained because the HVG was tested at the end of the week, which implies a greater swim-volume and training sessions than the LVG. However, the non-significant difference between groups for fatigue (p = 0.27) and sleep quality (p = 0.70) weaken this relationship. Fatigue and sleep disorders have been found in overtrained swimmers; during the peak swim-volume period of the season, self-reported impairments in sleep and fatigue predicted overtraining before the deterioration in performance became evident several weeks later. Furthermore, both have been reported as injury predictors in team sports. The results showed that the changes in both variables might be sensitive to higher swim-training volumes performed over the week. The increases in stress (fatigue) and simultaneous decreases in recovery (sleep) might increase the susceptibility to injury and overtraining. However, as a result of the non-significant difference between groups, swim-volume might weaken its contribution to these changes.

Overall wellness score (sum of the individual item scores of the Hooper questionnaire) was affected in both groups with large ES. Hooper et al. found that the overall score of this questionnaire accounted for 49%, 78%, and 76% of the variance to predict overtraining in swimmers in early, late and midseason respectively. Training loads can impose stress on the athlete, shifting their physical and psychological wellness along a continuum that progresses from acute fatigue to functional overreaching, non-functional overreaching, and ultimately overtraining syndrome. Therefore, these results support the importance of regularly monitoring these factors of potential overtraining in competitive swimmers. Finally, general stress was not affected over the week in any group. Likewise, a study in rowers found that a six-day heavy training camp negatively affected perceived fatigue and sleep quality but not the levels of general stress. This might be explained as increases in stress values related to training volume need longer periods to be affected.

Finally, it is important to consider the variability of the responses among swimmers. Although most swimmers decreased their shoulder physical qualities and wellness factors at follow-up, the responses were varied (Figures 1 and 2). Therefore, these findings further support the individual monitoring and management of training loads in competitive swimmers.

LIMITATIONS

This study presents several limitations. First, athletes usually experienced stress from sources other than training loads, such as academic, social, lifestyle, and athlete coach-relationship. Some of these factors could have also influenced the changes found in physical and wellness factors. Second, the monitoring period was short (one week) and does not reflect the long-term adaptations of the swimmers to training loads. Third, participants were assigned to each group by convenience and availability. Although this could have affected the baseline symmetry between groups due to confounding factors, the baseline characteristics were similar between groups. Fourth, the intensity and volume of the follow-up session could have influenced how swimmers recalled the single weekly report of RPE (e.g., a hard follow-up session could have led to a greater weekly RPE value). Despite this, the participants consistently reported higher weekly RPE values at the end of the week than during the week, weaken this assumption. Fifth, the age range of the participants (12-21 years) may have affected the results as maturational age can influence the response to training. Although the age frequency and average were similar between groups, it is not possible to determine biological maturation based on chronological age. Thus, how many swimmers in each group had reached or not reached biological maturation is unknown. Despite this, the age range of the participants can be also a strength as it represents the most common age in swimming squads (adolescents and young adults). Lastly, only the average of the results was calculated, which does not represent the individual responses to training encountered by each swimmer. Future research performing repeated measurements should investigate prospectively the individual changes in physical and wellness factors and examine how they are related to the development of shoulder pain in swimmers. Furthermore, it would be important to understand how long these factors take to recover after the stress induced by training loads.

CONCLUSIONS

The accumulation of training loads over a week negatively affected shoulder ER ROM and wellness factors (self-reported muscular soreness, fatigue, and sleep quality) in swimmers. Considering that shoulder ER ROM is a potential risk factor for shoulder pain and wellness factors have been associated with overtraining in swimmers, their regular monitoring might be necessary. This can potentially help to identify swimmers at greater risk of shoulder injury and overtraining. Regarding swim-volume, only the perception of training loads was different between groups. This shows that, although performing higher swim-volumes was perceived as harder, this did not reflect significant differences in general wellness and shoulder physical qualities between...
groups. The regular monitoring of subjective wellness along with objective physical qualities to assess swimmers’ response to the accumulation of training loads might be necessary.

CONFLICTS OF INTEREST
None

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REFERENCES


Original Research

Comparison of Glenohumeral Range of Motion Deficits in Youth, Collegiate, and Professional Baseball Players

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Keywords: pitching, throwing, sports medicine, sports, shoulder, injury, glenohumeral joint

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Background

Examining range of motion deficits across levels of baseball competition can result in a better understanding of the extent of altered range of motion patterns and identify competition levels that may require preventative interventions that target the deficits.

Purpose

The purpose of this study was to compare shoulder range of motion in baseball players across levels of competition and compare the prevalence of glenohumeral internal rotation deficit (GIRD) and total arc of motion differences (TAMD) between competition levels in pitchers and position players.

Study Design

Prospective descriptive cohort

Methods

Passive internal and external rotation range of motion was measured bilaterally. Individuals with current pain in the arm, shoulder, elbow or shoulder surgery within the prior two years were excluded. Measurements were taken during pre-season physical examinations. Players were divided into seven groups: 12u (11-12 years; n=30), 14u (13-14 years; n=30), High School 1 (HS 1; 15-16 year; n=42), High School 2 (HS 2; 17-18 years; n=25), College (n=22), Professional 1 (Pro1; 17-22 years; n=37) and Professional 2 (Pro2; 23 and older; n=37). Multiple one-way analyses of variance were performed to determine differences between groups. Tukey test for post-hoc analysis was employed to determine which competition levels were significantly different.

Results

Two-hundred and twenty-three male baseball players ages 11-26 participated. The 12u (53.7\(^\circ\)) and 14u (54.2\(^\circ\)) groups had significantly less internal rotation than HS1 (65.2\(^\circ\)), HS2 (63.9\(^\circ\)), College (62.3\(^\circ\)), Pro1 (64.9\(^\circ\)), and Pro2 (64.5\(^\circ\)) players (p<0.0001). The 12u, 14u, HS1, college, and Pro2 groups had greater than 50% of players with total arc of motion differences >5\(^\circ\).

Conclusions: Range of motion alterations exist across ages and levels of competition with 12u and 14u players having less internal rotation than the older groups and youth pitchers having less total range of motion than HS1.

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Comparison of Glenohumeral Range of Motion Deficits in Youth, Collegiate, and Professional Baseball Players

Level of Evidence
2

INTRODUCTION

The repetitive nature of throwing can result in altered glenohumeral range of motion patterns including increased external rotation (ER) and decreased internal rotation (IR) compared to the non-dominant arm.\textsuperscript{1–17} Glenohumeral internal rotation deficit (GIRD), defined as decreased IR greater than 20° in the throwing arm compared to the non-throwing arm, has been reported to be related to injury in professional baseball pitchers.\textsuperscript{17,18} Factors that have been suggested to contribute to GIRD are humeral retroversion,\textsuperscript{11,19,20} posterior capsular tightness,\textsuperscript{1,5,7} and muscular changes.\textsuperscript{12} GIRD has been associated with superior labral tears from anterior to posterior, as well as articular sided rotator cuff tears, biceps, and capsular injuries in players of all ability levels, from little league to professional players.\textsuperscript{6,21–23}

In addition to assessing for the presence of GIRD, total arc of motion is also a critical measure that should be considered by clinicians working with baseball players. Total arc of motion is obtained by adding the measures of ER and IR on one shoulder together rather than purely evaluating side-to-side IR loss. Shoulder range of motion may contribute to injury risk in baseball players, however conflicting evidence exists in the literature. Side-to-side total arc of motion differences (TAMD) > 5° is associated with increased injury risk in professional baseball pitchers.\textsuperscript{18} Decreased IR and total arc of motion has been demonstrated to contribute to upper extremity injury in youth, high school, and professional baseball players.\textsuperscript{6,21–23} However, a recent study of 832 high school baseball pitchers and position players indicated that range of motion deficits did not contribute to injury risk.\textsuperscript{24} The conflicting evidence indicates a need for further research on range of motion patterns between competition levels.

Improved understanding of range of motion alterations across ages and levels of competition may allow the identification of risk factors and development of interventions to decrease the incidence of upper extremity injuries in baseball players. No study to date has evaluated range of motion in cohorts of youth, high school, collegiate, and professional levels of competition as part of the same study. The current study is unique because youth, high school, and professional players are examined based on age and not solely on competition level. Previous researchers have examined a wide range of ages together without taking into consideration potential differences that may be present from a developmental standpoint. Baseball participation may vary between younger and older players within each level of competition. The purpose of this study was to compare shoulder range of motion in baseball players across levels of competition and compare the prevalence of GIRD and TAMD between competition levels in pitchers and position players. It was hypothesized that shoulder range of motion would be different between competition levels. Additionally, collegiate and professional pitchers would have a significantly increased prevalence of GIRD and TAMD compared to youth and pitchers would have a greater prevalence of GIRD and TAMD than position players due to making a greater number of maximal effort throws over time.

METHODS

Baseball players were recruited from local youth leagues, high schools, and colleges. In addition, professional (Minor League) baseball players from a single organization volunteered. Both pitchers and position players were recruited by word of mouth. Exclusion criteria included current pain in the arm, shoulder, elbow or shoulder surgery within the last two years. Individuals were excluded if they had a history of injury within the prior six months that did not require surgery, but did result is an absence from play. The Baptist Hospital-Pensacola institutional review board approved this study. Prior to data collection, all testing procedures were explained to each participant and informed consent was obtained. For participants who were less than 18 years old, parental consent and participant assent were obtained. A power analysis for a one-way ANOVA with seven groups was conducted in G*Power (Version 3.1.7; Dusseldorf, Germany) to determine a sufficient sample size using an alpha of 0.05, a power of 0.80, and a large effect size ($\eta^2 = 0.40$).\textsuperscript{25} The estimated total sample size was 98.

Players completed a questionnaire that included questions regarding height, weight, hand dominance, level of participation, main position, years pitched, percentage of teams’ games pitched, and history of elbow or shoulder surgery in the last two years. Passive glenohumeral IR and ER range of motion was measured. Glenohumeral range of motion was assessed with the participants supine on an examination table with the arm positioned at 90° of shoulder abduction and the elbow flexed to 90°. A bolster was placed under the distal humerus to maintain arm position in the plane of the scapula. The position of the scapula was controlled by palpating the coracoid process and monitoring for movement to determine the end range of glenohumeral motion.\textsuperscript{7,22,25,26–28} Measurements were recorded with a Baseline® digital inclinometer (Fabrication Enterprises, Inc., White Plains, NY) placed along the ulnar shaft with the hand in a pronated position for IR and the digital inclinometer along the ulnar border with the hand in the neutral position for ER.\textsuperscript{7,22,25,27} For all measurements, the inclinometer was placed proximal to the ulnar styloid. Once the end range of motion was reached, the value was recorded. Measurements were taken prior to the season, during preparticipation physical examinations, and participants were instructed to not throw or pitch 48 hours prior to testing. Participants did not perform any upper extremity stretching or warm-up exercises prior to testing. Youth, high school, and college participants had their measurement assessed in late July and professional pitchers had their measurements taken in March prior to spring training. Range of motion was assessed bilaterally and two measurements were recorded for each rotational motion.\textsuperscript{29} The average was then calculated and used for data analysis. A sin-
Table 1. Participant Demographics. Mean (SD).

<table>
<thead>
<tr>
<th>Group</th>
<th>Group Characteristics</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
<th>% Pitchers</th>
</tr>
</thead>
<tbody>
<tr>
<td>12u (n=30)</td>
<td>11-12 years old</td>
<td>12.0 (0.5)</td>
<td>153.7 (9.6)</td>
<td>49.2 (11.3)</td>
<td>63</td>
</tr>
<tr>
<td>14u (n=30)</td>
<td>13-14 years old</td>
<td>13.0 (0.5)</td>
<td>170.8 (8.9)</td>
<td>58.5 (12.2)</td>
<td>77</td>
</tr>
<tr>
<td>HS1 (n=42)</td>
<td>15-16 years old</td>
<td>15.0 (0.7)</td>
<td>176.2 (8.4)</td>
<td>69.5 (11.9)</td>
<td>52</td>
</tr>
<tr>
<td>HS2 (n=25)</td>
<td>17-18 years old</td>
<td>17.0 (0.7)</td>
<td>183.2 (5.6)</td>
<td>79.6 (9.1)</td>
<td>60</td>
</tr>
<tr>
<td>College (n=22)</td>
<td>College players</td>
<td>19.1 (0.9)</td>
<td>177.5 (26.1)</td>
<td>81.0 (18.2)</td>
<td>41</td>
</tr>
<tr>
<td>Pro 1 (n=37)</td>
<td>17-22 years old professional players</td>
<td>20.4 (1.3)</td>
<td>185.3 (5.4)</td>
<td>91.0 (8.7)</td>
<td>32</td>
</tr>
<tr>
<td>Pro 2 (n=37)</td>
<td>23 years and older professional players</td>
<td>24.9 (2.5)</td>
<td>186.2 (6.0)</td>
<td>94.6 (8.3)</td>
<td>30</td>
</tr>
</tbody>
</table>

Single, board-certified orthopaedic surgeon performed range of motion measurements to reduce measurement variability. A single examiner positioned the arm for all measurements to reduce measurement variability. Test-retest reliability was performed on seven individuals, prior to initiating the study, to determine intrarater reliability. The examiner reported excellent intrarater reliability for all range of motion measures, with intraclass correlation coefficient (ICC) and minimal detectable change (MDC): IR—ICC(3,2) = 0.94, MDC90 = 6.8°; ER—ICC(3,2) = 0.91, MDC90 = 7.8°; GIRD—ICC(3,2) = 0.95, MDC90 = 5.2°; TAMD—ICC(3,2) = 0.996, MDC90 = 5.5°.

Participants were divided into seven groups for analysis. The following groups were assigned: 12u (11-12 years; n=30), 14u (13-14 years; n=30), High School 1 (HS 1; 15-16 year; n=42), High School 2 (HS 2; 17-18 years; n=25), College (n=22), Professional 1 (Pro1; 17-22 years; n=37) and Professional 2 (Pro2; 23 and older; n=37). Data were analyzed using Statistical Package for the Social Sciences software (version 22; SPSS Inc., Chicago, IL, USA).

Means and standard deviations were calculated for each group’s IR and ER range of motion for both the dominant (throwing) and non-dominant arms. Differences in IR and ER values between arms were calculated, and the percentage of participants in each group with GIRD in the dominant arm >20° was calculated. Total arc of motion was calculated by the sum of IR and ER. The percentage of participants in each group with TAMD >5° and GIRD was also calculated. Multiple one-way analyses of variance (ANOVA) were performed to determine differences between groups. Tukey test for post-hoc analysis on significant findings was employed to determine which competition levels of baseball players were significantly different. A one-way ANOVA was also performed to determine if range of motion in pitchers was significantly different between competition levels. Chi-square tests were performed to examine the differences in prevalence of GIRD and TAMD between pitchers and position players. The significance level was p ≤ 0.05 for all analyses.

RESULTS

Participant demographics and characteristics across the seven groups (12u, 14u, HS1, HS2, College, Pro1, and Pro2) are presented in Table 1. Significant differences were observed in height and mass across the seven groups. Data describing dominant arm range of motion in baseball players are presented in Figure 1. Significant differences were observed in IR (p < 0.0001), ER (p = 0.038), and total arc of motion (p < 0.0001) measures between groups of baseball players. 12u and 14u players had significantly lower IR compared to the high school, collegiate and professional players. ER was significantly greater in 12u players compared to college players (mean difference = 7.1°). Total arc of motion was significantly less in 12u and 14u players compared to HS1 and Pro1 & Pro2 players. College baseball players had significantly less total arc of motion than Pro1 players. When examining side-to-side differences across groups (Table 2), significance was not reached for any measurement. 14u players had the highest prevalence of GIRD at 30.3% and 73.3% of 12u players had TAMD >5°.

Significant differences were observed in dominant arm range of motion of pitchers (Figure 2). IR was significantly less in 12u and 14u pitchers compared to HS1 and Pro1 pitchers (p<0.0001). 12u pitchers also had less IR than college pitchers (mean difference = 10.3°; p=0.0001). Total arc of motion was also significantly less for 12u and 14u pitchers compared to HS1 pitchers (mean difference (12u vs HS1) = 11.1°; mean difference (14u vs HS1) = 11.8°; p = 0.0004). No significant differences were found in side-to-side range of motion in pitchers (Table 3). The 14u group of pitchers had the highest prevalence of GIRD >20° (27.8%). More than 70% of 12u and Pro2 pitchers had TAMD >5°. Across all competition levels, 14.4% of position players had GIRD and 50% had TAMD >5°. For pitchers across all competition levels, 21% had GIRD and 58.1% had TAMD >5°. There was no
Comparison of Glenohumeral Range of Motion Deficits in Youth, Collegiate, and Professional Baseball Players

Table 2. Side-to-Side Difference in Range of Motion (°) between Groups. Mean (SD).

<table>
<thead>
<tr>
<th>Group</th>
<th>Glenohumeral Internal Rotation Difference</th>
<th>External Rotation Difference</th>
<th>Total Arc of Motion Difference</th>
<th>GIRD (%)</th>
<th>Total Arc of Motion Difference &gt; 5° (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12u</td>
<td>-13.1 (9.8)</td>
<td>6.7 (8.3)</td>
<td>-6.4 (11.6)</td>
<td>20</td>
<td>73</td>
</tr>
<tr>
<td>14u</td>
<td>-15.7 (10.2)</td>
<td>10.2 (9.7)</td>
<td>-5.5 (11.5)</td>
<td>30</td>
<td>53</td>
</tr>
<tr>
<td>HS1</td>
<td>-9.3 (7.8)</td>
<td>7.3 (7.1)</td>
<td>-2.0 (8.1)</td>
<td>17</td>
<td>52</td>
</tr>
<tr>
<td>HS2</td>
<td>-11.4 (7.5)</td>
<td>6.2 (6.1)</td>
<td>-5.2 (6.9)</td>
<td>16</td>
<td>40</td>
</tr>
<tr>
<td>College</td>
<td>-12.0 (8.6)</td>
<td>7.3 (7.4)</td>
<td>-4.7 (9.3)</td>
<td>18</td>
<td>50</td>
</tr>
<tr>
<td>Pro 1</td>
<td>-10.0 (7.4)</td>
<td>6.3 (7.2)</td>
<td>-3.7 (8.7)</td>
<td>14</td>
<td>43</td>
</tr>
<tr>
<td>Pro 2</td>
<td>-12.2 (9.5)</td>
<td>8.4 (10.2)</td>
<td>-3.8 (9.0)</td>
<td>24</td>
<td>60</td>
</tr>
</tbody>
</table>

Table 3. Side-to-Side Differences in Range of Motion (°) in Pitchers. Mean (SD).

<table>
<thead>
<tr>
<th>Group</th>
<th>Glenohumeral Internal Rotation Difference</th>
<th>External Rotation Difference</th>
<th>Total Arc of Motion Difference</th>
<th>GIRD (%)</th>
<th>Total Arc of Motion Difference &gt; 5° (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12u (n=20)</td>
<td>-14.2 (11.2)</td>
<td>7.7 (9.5)</td>
<td>-6.6 (12.6)</td>
<td>20</td>
<td>70</td>
</tr>
<tr>
<td>14u (n=18)</td>
<td>-13.6 (10.1)</td>
<td>10.8 (9.1)</td>
<td>-2.8 (9.93)</td>
<td>28</td>
<td>56</td>
</tr>
<tr>
<td>HS 1 (n=22)</td>
<td>-9.3 (7.7)</td>
<td>8.2 (8.2)</td>
<td>-1.1 (8.2)</td>
<td>10</td>
<td>55</td>
</tr>
<tr>
<td>HS 2 (n=14)</td>
<td>-11.9 (6.4)</td>
<td>7.3 (6.3)</td>
<td>-4.6 (6.7)</td>
<td>21</td>
<td>43</td>
</tr>
<tr>
<td>Col (n=9)</td>
<td>-15.7 (6.5)</td>
<td>12.7 (4.2)</td>
<td>-3.0 (7.3)</td>
<td>22</td>
<td>44</td>
</tr>
<tr>
<td>Pro 1 (n=12)</td>
<td>-11.9 (7.2)</td>
<td>5.8 (7.4)</td>
<td>-6.2 (8.6)</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>Pro 2 (n=11)</td>
<td>-17.9 (9.6)</td>
<td>12.8 (9.8)</td>
<td>-5.1 (7.9)</td>
<td>27</td>
<td>73</td>
</tr>
</tbody>
</table>

difference in the prevalence of GIRD between pitchers and position players (χ² = 1.7; p=0.199). There was also no difference in the prevalence of TAMD >5° between pitchers and position players (χ² = 1.5; p=0.226).

DISCUSSION

The most important finding of this study is that range of motion had little variation among the competition levels of baseball players and in the pitcher subgroup. The hypothesis that collegiate and professional players and pitchers would have a higher prevalence of GIRD and TAMD compared to youth was not supported however a few significant differences were observed between groups. Youth players (12u and 14u) had significantly less IR and total arc of motion than players in higher competition levels. IR and total arc of motion were also significantly less in youth (12u and 14u) pitchers compared to high school (HS1), college, and professional (Pro1) pitchers. The secondary hypothesis was also not supported because the prevalence of GIRD and TAMD >5° was similar between pitchers and position players.

Figures 2. Internal rotation(A), external rotation (B), and total arc of motion (C) of the dominant arm in pitchers. *Significantly greater than 12u. ^Significantly greater than 14u.

Decreased IR and ER range of motion with age in little league and adolescent baseball players ages 8-16 has been reported.10 In 10-12 year old pitchers, GIRD was present in 10 of the 25 players and there was no significant difference in ER compared to the non-dominant arm suggesting the loss of IR can occur prior to gains in ER.9 In contrast, the current results show greater IR from high school age and throughout the higher levels of competition, compared to
12u and 14u. Repetitive eccentric contractions of the posterior musculature during throwing can lead to tightness and postero-inferior capsular contracture may contribute to loss of IR. It is possible that the difference in IR was due to the relatively small sample size of participants in each age group. The increased IR in higher competition levels may also be related to an increased awareness of the importance of maintaining range of motion. Furthermore, from high school through the professional competition levels, players have access to medical and strength and conditioning personnel that can educate and stretching programs for players. Youth baseball players often do not have access to these resources.

Maintaining total arc of motion in the presence of GIRD may be more important than solely focusing on GIRD because gains in ER may compensate for loss of IR. Increased ER in the throwing shoulder compared to the non-throwing shoulder is an adaptation that has been reported in baseball players. Humeral retroversion is thought to be a contributing factor to increased ER and is an adaptation that may be due to participation in overhead sports before skeletal maturity occurs. Increased retroversion of the humerus along with increased external rotation in the dominant arms of the pitchers has previously been reported. ER range of motion was significantly greater in the 12u group compared to the college group, which was unexpected due to the physical changes that occur through maturation. It is assumed that the 12u group of players had not reached skeletal maturity and likely had not gain the benefit of the osseous adaptations that occur with throwing. TAMD >5° has been associated with increased injury risk in professional baseball pitchers but it is unclear if this cut-off value differentiates risk of injury in players in lower competition levels. The 12u, 14u, HS1, college, and Pro2 groups had greater than 50% of players with TAMD >5°. The 12u group had the highest percentage of players with TAMD (73%). Despite TAMD >5° frequently referenced in the literature this value may be within measurement error and have limited clinical significance.

Limitations of the study include that this was a cross-sectional study conducted at a single point in time comparing different competition levels of baseball players. Tanner staging was not performed to determine physical maturity of the players thus there could have been some overlap between players in the younger groups that may have affected the results. Another limitation to this study is the small sample of pitchers that were compared across competition levels. Youth baseball players frequently play multiple positions until higher levels of competition are reached and they transition to a single position. Future research should aim to longitudinally assess changes in range of motion and humeral retroversion in young baseball players over the course of their playing careers. This future research would allow for clinicians to gain a better understanding of the physiological adaptations that contributed to altered range of motion patterns in baseball players.

CONCLUSION

The results of this study indicate that range of motion was similar across competition levels of baseball players and the pitcher subgroup. More than 70% of the 12u and Pro2 groups had TAMD >5°. These results indicate that clinicians should monitor range of motion in all age groups of baseball players and pitchers.

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REFERENCES


Comparison of Glenohumeral Range of Motion Deficits in Youth, Collegiate, and Professional Baseball Players


Original Research

Shoulder and Hip Range of Motion and Strength Changes Throughout a Season in College Softball Players

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1 University of Florida

Keywords: strength, softball, shoulder, range of motion, hip, competitive season, change, movement system

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Background

Many studies have been done on the strength and mobility of the shoulder and hip in baseball players, but fewer studies have examined these metrics in softball players.

Purpose

The purpose of this study was to observe and analyze changes in range of motion (ROM) and strength at the hip and shoulder that occur over the course of a competitive season, to describe preseason ROM and strength at the hip and shoulder in healthy college softball players through side-to-side comparison, and to compare measurements between pitchers and position players.

Study Design

Descriptive Cohort Study

Methods

Data was collected over the course of six seasons, and a total of fifty-four healthy softball athletes (including pitchers and position players) who completed at least one set of preseason and postseason measurements were included. Subjects underwent passive ROM (External rotation [ER], internal rotation [IR], total arc of motion [TAM]) and strength (ER/IR at the shoulder, abduction/extension at the hip) measurements at preseason and postseason timepoints.

Results

Over a season, position players demonstrated an increase in all ROM metrics in both shoulders, except dominant IR, and a decrease in ER strength at the shoulder bilaterally (p<0.05). They also showed decreased ROM in all metrics across both hips (p<0.05). Pitchers had increased IR and TAM ROM in the dominant shoulder, decreased strength in both shoulders (ER throwing; ER and IR non-throwing), decreased ROM in both hips, and decreased abduction strength in the non-dominant hip (p<0.05). Position players showed less preseason IR in the dominant shoulder compared to non-dominant IR (Dominant: 31.7 ± 1.6°, Non-dominant: 37.0 ± 2.3°; p<0.05).

Conclusion

Softball pitchers and position players both show increased ROM at the shoulder and decreased ROM at the hip over the course of a season. Position players demonstrated side-to-side discrepancies and seasonal changes at the throwing shoulder similar to those seen in baseball players. The preseason mobility of the dominant shoulder of pitchers increased over the season while strength of hip abduction in the non-dominant side was...
Shoulder and Hip Range of Motion and Strength Changes Throughout a Season in College Softball Players

INTRODUCTION

Softball is a popular sport among athletes of all ages, and it is the third largest collegiate sport for women, making up roughly 9.3% of total female athletes in the National Collegiate Athletic Association (NCAA) according to statistics from 2019-2020 data. In a given year at the collegiate level, there are an estimated 20,800 female softball athletes participating in roughly 995 softball programs across the country, and 296 of these are Division I schools, 288 are Division 2, and 411 are Division 3. Based on annual statistics, these numbers have been steadily increasing over the past decade with a total athlete participation increase of 17.3%.

In baseball athletes, the overhead throwing motion is frequently associated with predictable adaptations at the shoulder joint on the throwing side which are believed to take place through a combination of humeral retroversion, posterior capsular thickening, and muscular tension. Additionally, reduced mobility and strength at the hip has been associated with impaired performance and injuries in both upper and lower extremities due to inappropriate compensation. While numerous studies have examined range of motion (ROM) and strength patterns in baseball players, few studies have explored these metrics in softball players. Even though the overhead throwing motion is similar for baseball players and softball position players, a study performed by Hibberd et al. showed that baseball players had significantly greater degrees of IR deficit and humeral retroversion when compared to softball position players. These results indicate that the physical adaptations in response to repeated overhead throwing in softball athletes may differ from baseball athletes. Therefore, performance training and injury prevention programs designed for baseball athletes may not be as effective for softball athletes.

In a study conducted by Oliver et al., ROM in the hip and shoulder joint in softball position players demonstrated significant side-to-side differences between throwing and non-throwing sides. However, no side-to-side differences were observed in pitchers. Since side-to-side deficiencies like glenohumeral internal rotational deficit and total arc motion deficit are associated with injury in overhead throwing athletes, position players may be at greater risk of injury when compared to pitchers. Some authors have suggested that the stress of the underhand windmill pitch may place pitchers at greater risk for shoulder injury than position players. Since there are distinct differences between the physical demands of pitchers and position players in softball, further study of how these athletes differ in terms of strength and mobility is warranted to help athletic trainers and team physicians design training and injury prevention programs.

Since Division I collegiate softball represents one of the most elite levels of competition in the sport, the information gathered from these athletes is important for understanding how strength and mobility correlates to performance. Some studies have described normal ROM and strength in softball players, but no studies have assessed how these metrics change over the course of a competitive season. The purpose of this study was to characterize range of motion (ROM) and strength at the shoulder and hip of healthy softball players and observe how these change after a competitive season, how they compare between throwing and non-throwing sides, and how they compare between pitchers and position players. By measuring change over a season, this study aims to better understand how the demands of a competitive season impact the strength and mobility profile of a healthy, competitive softball athlete.

METHODS

PARTICIPANTS

This was a longitudinal descriptive study including a prospective cohort of 54 college softball players who participated in at least one set of preseason and postseason measurements. Data were collected over the course of six competitive seasons with an average of 55 games played per regular season. Athletes were recruited from a single NCAA Division I softball team. Athletes were followed linearly as long as they had no reported injury or surgery within six months prior to preseason measurements and maintained active participation in their sport without reported injury. Because the purpose of this study was to characterize ROM and strength changes that occur in healthy athletes, athletes with recent injuries were excluded for concern that their measurements might alter the data due to ROM or strength limitations. A total of 54 healthy athletes were included, and no exclusions were made from preseason to postseason. A total of 127 player seasons were recorded.

MEASUREMENT PROCEDURES

Participation involved a preseason and postseason assessment of passive ROM and strength at the shoulder and hip joint. Preseason measurements were taken prior to any organized preseason workouts, and postseason measurements were taken prior to regional tournament play towards the end of the season. Athletes did not perform a warmup prior to having measurements taken. In athletes who participated for multiple seasons (37 out of 54 athletes), each pair of preseason and postseason measurements was classified as a separate player season. A two-tester method was used for all measurements with one tester who was present for all measurements, and each measurement was performed only one time to avoid the effects of fatigue from testing athletes through multiple repetitions. Therefore, no measurement error values were included.

For ROM measurements in the shoulder, a goniometer was used to determine degrees of deviation from a standard position. Passive internal rotation (IR) and external rotation (ER) measurements were performed with the athlete in a supine position with the shoulder abducted 90° and the
arm held in 90° of elbow flexion. One tester stabilized the scapula using a C-shaped grip with fingers on the posterior scapula and the anterior coracoid while passively moving the shoulder to end ROM in either internal or external directions. The second tester positioned the goniometer axis of rotation at the olecranon process with the stationary arm perpendicular to the table and the moving arm parallel to the shaft of the ulna. This technique, used in prior studies by this group of authors,13 has shown good interrater reliability with an intraclass correlation coefficient (ICC) of 0.43 and 0.88 for IR and ER measurements, respectively.14,15 Total arc of motion (TAM) was calculated by the sum of internal and external rotation in each shoulder.

For hip ROM, the athlete was placed in a prone position with hip at 0° of extension and abduction and the measured knee flexed at 90°. One tester stabilized the pelvis with one hand while rotating the hip passively until end ROM was reached. The second tester placed the bubble inclinometer proximal to the medial malleolus. The inclinometer was calibrated perpendicular to the plane of the table, and the reading was recorded at end ROM for hip rotation measurements. The axis of rotation was through the longitudinal shaft of the femur. This method, previously used by these authors in Zeppieri et al., has shown good interrater reliability with ICC of 0.98.16 TAM was calculated by the sum of IR and ER in each hip.

For strength measurements at the shoulder, a microFET 2 digital handheld dynamometer (Hoggan Health Industries, Salt Lake City, Utah) was utilized. The athletes were instructed to apply a maximal force against the force pad of the dynamometer for five seconds. To measure shoulder IR and ER strength, the athlete was positioned prone with their measured shoulder abducted at 90° and elbow held in 90° of flexion. One tester stabilized the scapula by placing a hand over the posterior aspect of the scapula while a second tester placed the force pad of the dynamometer on the volar aspect of the wrist for IR and the dorsal aspect of the wrist for ER. These techniques have shown excellent interrater reliability with ICC demonstrated between 0.93 and 0.99.17

To measure hip abduction strength, the athlete was positioned lying on their side with the leg to be measured on top, placed in a slightly extended and fully extended at the knee. The contralateral hip was positioned in 40° of flexion. One tester stabilized the pelvis with hands placed at the lumbar and anterior iliac while a second tester positioned the dynamometer force pad proximal to the lateral femoral condyle. The subject performed a maximal muscle contraction against the dynamometer force pad for five seconds to record a result. To measure hip extension strength, the athlete was positioned prone with their measured hip at 0° extension and knee held at 90° of flexion. One tester stabilized the pelvis at the lumbar spine while the second tester positioned the dynamometer force pad proximal to the popliteal fossa, and the subject performed a maximal muscle contraction against the force pad for five seconds. These methods, previously used by these authors and Zeppieri et al., has shown a good interrater reliability reported by Krause et al. who reported good interrater reliability for hip abduction strength (ICC = 0.86-0.92) and hip extension strength (ICC = 0.91-0.95) and good intrarater reliability for hip abduction strength (ICC = 0.81) and hip extension strength (ICC = 0.88).18,19

### DATA ANALYSIS

Descriptive statistics were calculated for selected demographic variables. A paired, two-tailed t-test was used to calculate differences in shoulder and hip ROM and strength between preseason and postseason. Preseason to postseason changes were analyzed based on 127 individual player seasons where each athlete's preseason data was matched to that same athlete's postseason data. Paired, two-tailed t-test with equal variance was used to compare differences between dominant and non-dominant preseason shoulder and hip ROM and strength. Preseason averages for the pitcher group and player group were calculated using a weighted average method to account for certain athletes who completed more preseason measurements than others. For example, a weighted average value for an athlete participating for three seasons was calculated as follows:

\[
\text{TAM}_{1} + \text{TAM}_{2} + \text{TAM}_{3} \quad 3 \text{ seasons}
\]

Unpaired two-tailed t-test assuming unequal variance was used to compare preseason pitchers to position players shoulder and hip ROM and strength. Preseason averages for pitcher and position player groups were calculated using the same weighted average method as described previously. Given the multiple t-tests performed comparing side-to-side data and pitchers to position players, a Bonferroni correction was performed to adjust the \( \alpha \) value and minimize the likelihood of Type I error.

### RESULTS

#### SAMPLE DESCRIPTION

The number of total subjects, type of player, and player seasons are shown in Table 1 along with descriptive statistics of age, weight, height, side dominance.

### PRESEASON TO POSTSEASON CHANGE

In position players, ROM for ER and TAM increased on dominant (D) and non-dominant (ND) sides (D ER change = +2.5°, \( p = 0.05 \); D TAM change = +4.0°, \( p = 0.009 \); ND ER change = +5.3°, \( p = 0.009 \); ND TAM change = +5.8°, \( p = 0.001 \)). IR increased significantly in the non-dominant side.

---

### Table 1. Descriptive statistics of softball athletes

<table>
<thead>
<tr>
<th>Sample</th>
<th>54 total athletes</th>
<th>43 Position players</th>
<th>11 Pitchers</th>
<th>127 player seasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>19.6 ± 0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (inches)</td>
<td>66.7 ± 0.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (pounds [lb])</td>
<td>160.9 ± 3.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant arm</td>
<td>46 Right</td>
<td>8 Left</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Numbers represent mean ± 95% confidence interval.
(ND IR change = +2.6°, p = 0.013) but not the dominant throwing side (p = 0.086).

At the hip, ROM decreased significantly on both dominant and non-dominant sides (D ER change = -2.0°, p = 0.046; D IR change = -2.2°, p = 0.009; D TAM change = -4.2°, p < 0.001; ND ER change = -2.5°, p = 0.004; ND IR change = -5.2°, p < 0.001; ND TAM change = -5.7°, p < 0.001).

Decreased strength of ER at the shoulder was noted bilaterally (D ER change = -5.0 lb, p < 0.001; ND ER change = -2.3 lb, p < 0.001). The position player data from preseason to postseason comparison is summarized in Table 2, and a graphical representation is shown in Figures 1 and 2.

In pitchers at the shoulder, there was a significant increase in dominant side ROM for IR and TAM (D IR change = +5.6°, p = 0.002; D TAM change = +6.8°, p = 0.016). In the hip, there was a decrease in ER at the dominant side (D ER change = -6.7°, p = 0.001), and a significant decrease in TAM was noted in both sides (D TAM change = -6.9°, p = 0.004; ND TAM change = -6.2°, p = 0.006).

A decrease in both ER and IR strength was noted in the non-dominant shoulder (ND ER change = -5.3 lb, p < 0.001; ND IR change = -4.9 lb, p = 0.002) and a decrease in ER strength was seen in the dominant throwing shoulder (D ER change = -1.9 lb, p = 0.045). There was a decrease in strength of hip abduction in the non-dominant hip (ND Abd change = -5.0 lb, p = 0.001). The data for preseason to postseason change in pitchers is summarized in Table 2, and a graphical representation of the data is shown in Figures 3 and 4.

### SIDE TO SIDE DATA

The comparison of dominant to non-dominant side in position players showed less IR in the dominant shoulder (IR mean difference = 5.5°, p < 0.001) but greater ER than the non-dominant side (ER mean difference = 4.5°, p = 0.029). Of note, the lesser IR in the dominant shoulder was the only difference which was significant after Bonferroni correction. The data comparing side to side measurements in position players are summarized in Table 3.

The comparison of dominant to non-dominant side in pitchers revealed no significant differences across all mea-

### Table 2. Preseason to postseason changes

<table>
<thead>
<tr>
<th></th>
<th>Position Players</th>
<th>Pitchers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preseason ± 95% CI</td>
<td>Postseason ± 95% CI</td>
</tr>
<tr>
<td><strong>Shoulder ROM (°)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ND</td>
<td>37.9 ± 2.1</td>
<td>40.5 ± 1.9</td>
</tr>
<tr>
<td>D</td>
<td>32.1 ± 1.6</td>
<td>33.8 ± 1.7</td>
</tr>
<tr>
<td>ER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ND</td>
<td>97.3 ± 2.3</td>
<td>100.6 ± 2.6</td>
</tr>
<tr>
<td>D</td>
<td>101.7 ± 1.9</td>
<td>104.0 ± 2.3</td>
</tr>
<tr>
<td>TAM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ND</td>
<td>135.2 ± 2.9</td>
<td>141.0 ± 3.0</td>
</tr>
<tr>
<td>D</td>
<td>133.8 ± 2.7</td>
<td>137.8 ± 2.7</td>
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<tr>
<td><strong>Hip ROM (°)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ND</td>
<td>16.3 ± 1.4</td>
<td>13.1 ± 1.7</td>
</tr>
<tr>
<td>D</td>
<td>15.2 ± 1.2</td>
<td>13.0 ± 1.4</td>
</tr>
<tr>
<td>ER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ND</td>
<td>21.0 ± 1.5</td>
<td>18.5 ± 1.4</td>
</tr>
<tr>
<td>D</td>
<td>20.8 ± 1.8</td>
<td>18.8 ± 1.6</td>
</tr>
<tr>
<td>TAM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ND</td>
<td>37.3 ± 2.2</td>
<td>31.6 ± 2.0</td>
</tr>
<tr>
<td>D</td>
<td>35.9 ± 2.1</td>
<td>31.7 ± 2.2</td>
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<tr>
<td><strong>Shoulder Strength (lb)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ND</td>
<td>20.8 ± 1.1</td>
<td>18.5 ± 1.2</td>
</tr>
<tr>
<td>D</td>
<td>21.0 ± 1.2</td>
<td>18.0 ± 1.2</td>
</tr>
<tr>
<td>ER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ND</td>
<td>19.6 ± 1.0</td>
<td>19.2 ± 1.2</td>
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<tr>
<td>D</td>
<td>20.1 ± 1.1</td>
<td>19.3 ± 1.3</td>
</tr>
<tr>
<td><strong>Hip Strength (lb)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ND</td>
<td>41.1 ± 1.7</td>
<td>42.4 ± 1.7</td>
</tr>
<tr>
<td>D</td>
<td>42.4 ± 1.5</td>
<td>43.9 ± 1.7</td>
</tr>
<tr>
<td>Ext</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ND</td>
<td>35.4 ± 1.4</td>
<td>35.2 ± 1.5</td>
</tr>
<tr>
<td>D</td>
<td>37.0 ± 1.5</td>
<td>36.2 ± 1.5</td>
</tr>
</tbody>
</table>

IR = Internal Rotation; ER = External Rotation; TAM = Total Arc of Motion; Abd = Abduction; Ext = Extension; CI = confidence interval; ND = Non-dominant; D = Dominant

* Denotes statistically significant difference

lb = pounds
Measurements of ROM and strength at the shoulder and hip (p > 0.05). The data from side-to-side comparison in pitchers are summarized in Table 3.

POSITION VS. PLAYER

Comparing ER at the shoulder in the dominant throwing arm, position players had greater ER when compared to pitchers (Position Dominant ER = 101.8° ± 2.5; Pitcher Dominant ER = 92.4° ± 6.8; p = 0.015). Position players had greater TAM in the dominant throwing arm compared to pitchers (Position Dominant TAM = 133.4° ± 3.2; Pitcher Dominant TAM = 124.3° ± 6.3; p = 0.012). The ROM of IR did not demonstrate any significant difference. Lastly, pitchers demonstrated significantly greater hip abduction strength in their non-dominant side when compared to position players (Position Non-Dominant Abd = 39.8 ± 2.2 lb; Pitcher Non-Dominant Abd = 45.1 ± 4.4 lb; p = 0.032). The results comparing position players and pitchers are summarized below in Table 4. No comparisons between pitchers and position players reached significance following Bonferroni correction.
DISCUSSION

The purpose of this study was to identify changes in ROM and strength at the hip and shoulder in healthy collegiate softball athletes over a season and to describe side-to-side differences and differences between pitchers and position players across these metrics. In comparison to previous studies examining preseason passive total arc of motion in the dominant shoulder of softball athletes which range from 132.9° to 156.4° in position players and 140.5° to 153.2° in pitchers, this study found similar throwing side passive shoulder total arc of motion values in position players (133.4°) but lesser values for pitchers (124.2°). The results of this study help further characterize the mobility and strength of the hip and shoulder in the softball athlete, and this study has identified certain variables where significant change occurred over the course of a competitive season. Since this descriptive data represents the healthy, competitive athlete, it may be valuable for identifying athletes who demonstrate abnormal mobility or strength measurements and may be at risk for reduced performance potential or injury. Ultimately, understanding the physical profile of these elite athletes and how they change throughout a season will help inform training programs and injury risk assessment.

Analysis comparing preseason to postseason in position players showed significant increase in range of motion across all measurements in the shoulder except for internal rotation of the dominant throwing side shoulder. This finding is consistent with existing literature which shows that the repetitive stress in an externally rotated, overhead throwing motion throughout a season causes limited internal rotation due to increased laxity of the anterior gleno-
humeral joint capsule with tightening of the posterior capsule and adaptive humeral retroversion.\textsuperscript{4,11,21–24} Interestingly, there was still increased range of motion across all shoulder measurements in position players over the course of the season in this study. These results support the findings by Dwelly et al. which demonstrated bilateral increased external rotation and total arc of motion without significant increase in internal rotation in the throwing side when studying various overhead throwing athletes over a competitive season.\textsuperscript{11} The results from this study and the study performed by Dwelly et al. differ from some studies in competitive season.\textsuperscript{26} Therefore, the results from this study indicate that the activities of a competitive softball season lead to increased range of motion across both shoulder joints in position players, but the repeated stress of the overhead throwing motion performed by position players likely contributes to the relative limitation of internal rotation. This altered range of motion could potentially lead to altered biomechanics during the throwing motion and eventual impingement or labral pathology.\textsuperscript{4} Since the results of this study show that shoulder strength decreased symmetrically in both dominant and non-dominant shoulders, the loss of strength may be due to factors related to in-season strength and conditioning rather than the repetitive, asymmetric throwing motion.

In pitchers, a significant increase in total arc of motion occurred from preseason to postseason in the dominant throwing shoulder, mostly due to the significant increase of internal rotation. This change indicates that the limited preseason throwing side range of motion is susceptible to change in response to the physical stress of pitching throughout a season. The increased ROM maybe due to a combination of tightened muscles of shoulder adduction and internal rotation based on healthy pitching mechanics described by Oliver et al.,\textsuperscript{25} and also loosening of external rotator muscles in the throwing side shoulder. The significant decrease of external rotational strength in the dominant throwing side with preserved internal rotation strength seen in our study further supports this theory. Based on these results, pitchers seem to improve their relative glenohumeral internal rotational deficit during a competitive season.\textsuperscript{3} Since this deficit has been demonstrated to confer risk of shoulder injury in baseball players,\textsuperscript{3} an internal rotation stretching program which has been shown to improve internal rotational deficits in baseball players\textsuperscript{26} may be more beneficial to implement in the offseason. However, further study needs to be done to identify specific risk factors for upper extremity injury in softball pitchers.

In position players, range of motion in the hip is globally reduced bilaterally over the course of a playing season. Pitchers show reduced dominant side external rotation and bilaterally decreased total arc of motion. Since studies of baseball athletes demonstrate association between decreased range of motion at the hip and injuries to the hip, groin and lower extremity,\textsuperscript{6} implementation of stretching programs during the competitive season may be a reasonable strategy to mitigate this increased risk of injury, especially in position players who experienced globally reduced range of motion in the lower extremity in this study.

Pitchers also show decreased hip abduction strength in the non-throwing side after a season (Pre = 43.8 ± 3.5 lb; Post = 38.8 ± 3.7 lb; p = 0.001). However, hip extension strength is well preserved from preseason to postseason. This change in hip abduction strength may be due to the

### Table 3. Side-to-side comparison of preseason data

<table>
<thead>
<tr>
<th></th>
<th>Position Players</th>
<th>Pitchers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-Dominant ± 95% CI</td>
<td>Dominant ± 95% CI</td>
</tr>
<tr>
<td><strong>Shoulder ROM (°)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR</td>
<td>37.0 ± 2.3</td>
<td>31.7 ± 1.6</td>
</tr>
<tr>
<td>ER</td>
<td>97.3 ± 3.2</td>
<td>101.8 ± 2.5</td>
</tr>
<tr>
<td>TAM</td>
<td>133.8 ± 3.9</td>
<td>133.4 ± 3.2</td>
</tr>
<tr>
<td><strong>Hip ROM (°)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR</td>
<td>15.5 ± 1.8</td>
<td>14.8 ± 1.7</td>
</tr>
<tr>
<td>ER</td>
<td>21.8 ± 1.8</td>
<td>21.6 ± 2.1</td>
</tr>
<tr>
<td>TAM</td>
<td>37.4 ± 2.8</td>
<td>36.3 ± 2.8</td>
</tr>
<tr>
<td><strong>Shoulder Strength (lb)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ER</td>
<td>19.9 ± 1.8</td>
<td>19.8 ± 1.8</td>
</tr>
<tr>
<td>IR</td>
<td>19.1 ± 1.4</td>
<td>19.1 ± 1.8</td>
</tr>
<tr>
<td><strong>Hip Strength (lb)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abd</td>
<td>39.8 ± 2.2</td>
<td>41.4 ± 2.0</td>
</tr>
<tr>
<td>Ext</td>
<td>34.4 ± 1.8</td>
<td>35.9 ± 1.9</td>
</tr>
</tbody>
</table>

IR = Internal Rotation; ER = External Rotation; TAM = Total Arc of Motion; Abd = Abduction; Ext = Extension; CI = confidence interval
* Denotes statistically significant difference
** Denotes statistically significant difference following Bonferroni correction (α = 0.0025)
+ Denotes degrees
lb = pounds
From preseason data analyzing side-to-side differences, position players demonstrated greater external rotation ROM with lesser internal rotation ROM in their dominant throwing arm compared to their non-dominant arm. The significance of the internal rotation difference was more prominent since it was upheld after Bonferroni correction while the external rotation difference was not. However, the total arc of motion was similar between throwing and non-throwing sides, these results did not show any significant glenohumeral internal rotation deficit. As opposed to baseball literature which shows that the most significant predictor for injury was a lack of relatively greater external rotation (<5°) in the throwing shoulder compared to non-throwing shoulder, this study shows a preseason average difference of only 4.5° and only 3.4° in postseason data. Since these are healthy softball athletes without injury, the data from this study indicates that the side-to-side ROM discrepancies at the shoulder joint of softball position players may be less significant than those seen in baseball pitchers. This distinction may be due to differences in throwing speed, biomechanical differences between male and female athletes, and workload differences between the sports. Further study comparing healthy softball position players to those with injuries is needed to determine if the same injury risk factors seen in baseball pitchers are applicable to softball athletes.

In the comparison between pitchers and position players, external rotation and total arc of motion at the shoulder appeared significantly greater in position players (analysis with a standard t-test), which is consistent with previous studies on overhead athletes and softball athletes; however, this difference was not signif-

### Table 4. Pitcher vs. position player comparison of preseason measurements

<table>
<thead>
<tr>
<th>Shoulder ROM (°)</th>
<th>Position</th>
<th>Pitcher</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR</td>
<td>Non-Dominant</td>
<td>37.0 ± 2.3</td>
<td>38.8 ± 5.0</td>
</tr>
<tr>
<td>Dominant</td>
<td>31.7 ± 1.6</td>
<td>31.9 ± 6.7</td>
<td>0.941</td>
</tr>
<tr>
<td>ER</td>
<td>Non-Dominant</td>
<td>97.3 ± 3.2</td>
<td>95.8 ± 9.9</td>
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<tr>
<td>Dominant</td>
<td>101.8 ± 2.5</td>
<td>92.4 ± 6.8</td>
<td>0.013*</td>
</tr>
<tr>
<td>TAM</td>
<td>Non-Dominant</td>
<td>133.8 ± 3.9</td>
<td>134.5 ± 8.5</td>
</tr>
<tr>
<td>Dominant</td>
<td>133.4 ± 3.2</td>
<td>124.3 ± 6.3</td>
<td>0.012*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hip ROM (°)</th>
<th>Position</th>
<th>Pitcher</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR</td>
<td>Non-Dominant</td>
<td>15.5 ± 1.8</td>
<td>15.5 ± 3.5</td>
</tr>
<tr>
<td>Dominant</td>
<td>14.8 ± 1.7</td>
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<td>0.939</td>
</tr>
<tr>
<td>ER</td>
<td>Non-Dominant</td>
<td>21.8 ± 1.8</td>
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<tr>
<td>Dominant</td>
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<td>0.416</td>
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<tr>
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<td>Non-Dominant</td>
<td>37.4 ± 2.8</td>
<td>35.0 ± 4.0</td>
</tr>
<tr>
<td>Dominant</td>
<td>36.3 ± 2.8</td>
<td>37.7 ± 2.9</td>
<td>0.472</td>
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</table>

<table>
<thead>
<tr>
<th>Shoulder Strength (lb)</th>
<th>Position</th>
<th>Pitcher</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER</td>
<td>Non-Dominant</td>
<td>19.9 ± 1.8</td>
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<td>Dominant</td>
<td>19.8 ± 1.8</td>
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<tr>
<td>Dominant</td>
<td>19.1 ± 1.4</td>
<td>20.0 ± 5.8</td>
<td>0.767</td>
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<th>Pitcher</th>
<th>p-value</th>
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<td>Abd</td>
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<td>39.8 ± 2.2</td>
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<td>35.2 ± 5.8</td>
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<tr>
<td>Dominant</td>
<td>35.9 ± 1.9</td>
<td>36.5 ± 5.6</td>
<td>0.818</td>
</tr>
</tbody>
</table>

IR = Internal Rotation; ER = External Rotation; TAM = Total Arc of Motion; Abd = Abduction; Ext = Extension; CI = confidence interval
* Denotes statistically significant difference
** Denotes statistically significant difference following Bonferroni correction (α = 0.0025)
° Denotes degrees
lb = pounds

* Demand of non-throwing side hip abduction strength in the windmill pitching motion. In a study examining the changes in hip ROM and strength before and after a game, Oliver et al. showed that pitchers had significantly reduced strength measures in their non-dominant hip.\(^2\) Further analysis of muscle activation during various phases of the pitching motion has shown that gluteus medius engagement is maximized during the planting phase, which is believed to be an important phase for stability and energy transfer from the hip to the upper extremity.\(^2\,^8,^9\) Therefore, it may be reasonable to consider implementation of specific hip abductor strength and conditioning strategies to maintain better strength throughout the season and maximize performance in pitchers.

From preseason data analyzing side-to-side differences, position players demonstrated greater external rotation ROM with lesser internal rotation ROM in their dominant throwing arm compared to their non-dominant arm. The significance of the internal rotation difference was more prominent since it was upheld after Bonferroni correction while the external rotation difference was not. However, the total arc of motion in both dominant and non-dominant shoulders was similar, which is consistent with literature on baseball players.\(^3,\,\,^2\) Since the side-to-side difference in internal rotation remained relatively small (<6°) and the total arc of motion was similar between throwing and non-throwing sides, these results did not show any significant glenohumeral internal rotation deficit. As opposed to baseball literature which shows that the most significant predictor for injury was a lack of relatively greater external rotation (<5°) in the throwing shoulder compared to non-throwing shoulder, this study shows a preseason average difference of only 4.5° and only 3.4° in postseason data. Since these are healthy softball athletes without injury, the data from this study indicates that the side-to-side ROM discrepancies at the shoulder joint of softball position players may be less significant than those seen in baseball pitchers. This distinction may be due to differences in throwing speed, biomechanical differences between male and female athletes, and workload differences between the sports. Further study comparing healthy softball position players to those with injuries is needed to determine if the same injury risk factors seen in baseball pitchers are applicable to softball athletes.
significant after applying a Bonferroni correction which was needed due to multiple comparisons. In this study, it seems that the total arc of motion difference between pitchers and position players was mostly explained by the greater external rotation in position players, but pitchers also seemed to show relatively reduced internal rotation in their dominant throwing shoulder. It is possible that this reduced range of motion represents physical adaptation in response to the unique stress of the windmill pitch. These results are similar to those found in a study of windmill pitchers performed by West et al., but West did not find a statistically significant side-to-side difference in mobility of the throwing shoulder. The comparison to position players in our study helps show that there may be a subtle reduction in mobility of the throwing shoulder in pitchers due to the dynamics of the windmill pitch. Since pitchers with upper extremity pain were shown to have greater shoulder abduction and distraction during foot contact and ball release when compared to pitchers without pain in a study by Oliver et al., greater muscular tension leading to reduced mobility in the throwing shoulder is most likely a positive adaptation for injury prevention seen in healthy pitchers in this study.

When compared to position players, pitchers showed significantly greater hip abduction strength in the non-throwing side; however, this difference was not significant after Bonferroni correction. Based on the symmetric strength in pitchers, this small difference is mostly due to a slight side-to-side disparity in position players who are weaker on the non-throwing side. This is likely due to the difference in throwing mechanics between the windmill softball pitch and the overhead throwing motion. Studies analyzing the softball pitching motion describe the importance of hip abduction strength in both throwing and non-throwing hips as it relates to maximum force delivery to the upper extremity; therefore, pitchers may benefit from training designed to increase hip abduction strength.

LIMITATIONS

While several statistically significant findings were identified through this study, there are a few limitations. The position players were not separated by the specific position they play. Athletes were also not stratified by differences in their in-season workload. This cohort of subjects was not large enough to generate enough statistical power to divide the subjects into position specific groups. However, all position players share a similar overhead throwing technique. Therefore, data gathered from this group may apply broadly to healthy softball athletes who repeatedly use an overhead throw. Additionally, the group of pitchers (n) was significantly smaller than the position players, so statistically significant differences were more difficult to demonstrate in this group. However, this sample size was still adequate to demonstrate changes in certain metrics over a season. Also, the use of player seasons for the preseason to postseason analysis allowed for certain subjects to be accounted for more than others. Therefore, changes observed in this analysis may be skewed by athletes who participated in the study through multiple seasons. Ultimately, these subjects represent the more healthy, durable athletes since they remained injury free for multiple seasons, so their influence is valuable for defining the healthy softball athlete.

In the measurement procedures, only one repetition was performed for each ROM or strength measurements. This prevented the inclusion of measurement error in the data analysis. Additionally, the technique for strength measurement using the microFET 2 dynamometer was not performed against a solid structure, therefore the measurements may have been limited by the strength of the tester. Also, these measurements were not taken at a specific time point with respect to competition and workouts since this was logistically difficult to replicate each year of the study. However, they were consistently taken under similar conditions at a date soon before preseason workouts began without warm-up.

FUTURE RESEARCH

Since this study was performed strictly in healthy subjects, future study including athletes with reported injuries during the season would help identify associations between injury and mobility and strength at the shoulder and hip. Also, study of in-season workload statistics like pitch count and workouts may help identify which specific activities are associated with the observed changes, and the effect of specific stretching and strengthening programs to mitigate the seasonal loss of strength or mobility may be studied. To better characterize the permanence of changes that take place over the course of a season, further study should be conducted to analyze the trend over the course of multiple seasons.

CONCLUSIONS

Softball pitchers and position players have unique mobility and strength profiles at the hip and shoulder. These profiles also demonstrate predictable changes over the course of a competitive season, and those changes are characterized generally by increased ROM at the shoulder, decreased ROM at the hip, and different patterns of decreased strength between groups. Position players showed similar changes to those observed in baseball players at the shoulder, but to a lesser extent in ROM change and side-to-side disparity. Pitchers showed preseason limited mobility in the shoulder which improved over the course of the season while losing hip abduction strength in the non-dominant hip. Ultimately, these observations taken in healthy, injury-free athletes may inform future position-specific training, stretching, and injury prevention programs in softball athletes.

DISCLOSURES

This study was approved by the University of Florida Health Science Center Institutional Review Board (IRB-01).

CONFLICTS OF INTEREST

None
REFERENCES


The Reliability and Validity of a Clinical Measurement Proposed to Quantify Humeral Torsion

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Keywords: range of motion, overhead athlete, shoulder, humeral torsion

Background

Range of motion (ROM) impairments of the overhead athletes’ shoulder are commonly addressed through mobility-based treatments, however, adaptations from humeral torsion (HT) are not amenable to such interventions. A clinical measurement to quantify HT has been proposed, however, the validity is not conclusive.

Purpose

The primary aim of this study is to determine the intrarater reliability and standard error of measurement (SEM) of the biceps forearm angle (BFA) measurement. The secondary aim of this study is to investigate the convergent validity of the BFA compared to diagnostic ultrasound.

Study Design

Cross Sectional Reliability and Validity Study

Methods

HT measurements, utilizing diagnostic ultrasound, were compared to BFA in 74 shoulders (37 subjects) over two sessions. Each measurement was performed three times and a third investigator recorded measures to ensure blinding. Reliability was investigated using utilizing an intraclass correlation coefficient (ICC 3,k)

Results

Intrarater reliability values were 0.923 and 0.849 for diagnostic ultrasound and BFA methods respectively. Convergent validity was $r = 0.566$. The standard error of measurement for diagnostic ultrasound and BFA was 3° and 5°, respectively. The 95% limits of agreement between the two measurement methods were -24.80° and 19.80° with a mean difference of -2.50° indicating that on average the diagnostic ultrasound measurement was lower than that of the BFA method.

Conclusion

The BFA is a reliable clinical method for quantifying HT, however, demonstrates moderate to poor convergent validity when compared to diagnostic ultrasound.

Level of Evidence

2b

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INTRODUCTION

Shoulder pain affects up to 67% of the adult population throughout their lifespan. The etiology of shoulder pain is multifactorial and inclusive of numerous impairments, including but not limited to, restricted mobility. Posterior shoulder tightness (PST), in particular, has been associated with more common diagnoses such as labral tears, rotator cuff related pain syndrome, and post-operative arthrofibrosis among both the general and athletic populations, with a predilection towards overhead athletes. PST has been defined as a limitation of the extensibility within the posterior soft tissue structures of the shoulder including both contractile and non-contractile elements as well as osseous changes seen in the form of humeral torsion (HT) within the overhead athlete through training adaptations. Moreover, PST has been associated with restricted internal rotation (IR), horizontal adduction (HA), and flexion range of motion in conjunction with increased external rotation (ER) in the dominant arm of the overhead athlete. Adaptive changes occurring within the throwing athletes shoulder complex have been studied extensively. Range of motion (ROM) adaptations within the throwing shoulder of baseball pitchers has gained significant attention in the literature, as these anatomical changes are relevant for both diagnosis and program design. These adaptations within the dominant arm of the overhead athlete are necessary to a certain extent in order to perform at a particular level. However, excessive adaptations in ROM, or lack thereof, have been proposed as possible risk factors for both shoulder and elbow injuries among baseball pitchers resulting in lost playing time.

Given the association between PST and shoulder pain in overhead athletes, sports medicine professionals often seek to quantify, and when necessary, decrease PST as a key element of their interventions. Within the overhead athlete it is necessary to determine which training adaptations surrounding the shoulder complex are contributing to differing degrees of mobility when compared to the non-throwing shoulder. There have been a number of proposed methods utilized to quantify PST; however, a recent systematic review provides evidence to support the use of a comprehensive approach including measures of HA, IR, and HT among the overhead athlete population. Once these elements have been identified, a thorough intervention strategy can be implemented in order to address any limitations. While soft tissue limitations may be addressed through select interventions, excessive adaptations in ROM resulting from HT are not amenable to mobility-based treatments. Identifying the contribution of HT to mobility impairments may serve to influence interventions and guide ROM expectations. HT can be measured utilizing computed tomography (CT) and diagnostic ultrasound by determining the angle created by the forearm and the proximal humerus. However, these methods require costly imaging investments and training, thus are not readily available in many clinical settings. Dashottar and Borstaf proposed a clinical method for quantifying HT, which is referred to as the biceps forearm angle (BFA) and relies on palpation of the bicipital tuberosities and does not require the use of imaging modalities. Conflicting evidence surrounding the degree of validity found within this measurement technique exists, lending uncertainty to its use as a practical alternative to ultrasound. Finally, a recent study by Yaaari et al. utilized both the palpation and ultrasound methods for measuring HT among baseball pitchers concluding that the palpation method significantly underestimated HT compared to diagnostic US. The current investigation utilized a general population with a majority of individuals having participated in various overhead sports in the past. The authors hypothesize that BFA method, utilizing palpation, for quantifying HT will demonstrate good validity when compared to diagnostic ultrasound as well as good intrarater reliability. The primary aim of this study is to determine the intrarater reliability and standard error of measurement (SEM) of the BFA measurement. The secondary aim of this study is to investigate the convergent validity of the BFA compared to diagnostic ultrasound.

METHODS

PARTICIPANTS

A convenience sample of 37 adults, 15 males and 22 females, mean age 24 (± 2.4) for a total of 74 shoulders were screened for eligibility in this study between February 2019 - May 2019. Of the 37 participants, 26 had previously participated in overhead sports. The inclusion criteria for this study consisted of individuals enrolled at the University of Indianapolis, graduate or undergraduate courses, age 18 – 40 years old, and able to assume all testing positions. Exclusion criteria for this study consisted of a history of or current shoulder pain or injury that had required the attention of a healthcare provider within the past year. Demographic data were collected from each participant including gender, age, height, body mass, and handedness. The mean ± standard deviation (SD) age, body mass index, and height for subjects was 24 ± 3 years, 24.93 ± 3.16 kg/m², and 171.76 ± 11.30 cm respectively with 35 individuals being right-handed and two individuals being left-handed. All participants that met the inclusion criteria and agreed to participate in the study were provided with and signed an informed consent form approved by the Institutional Review Board at the University of Indianapolis, Study #0906. All 37 participants that agreed to participate in the study were available for follow up.

INSTRUMENTS

A standard plinth and Baseline® digital inclinometer (Fabrication Enterprises, White Plains, NY) were utilized to quantify all ROM measurements. The digital inclinometer was set at a zero point along a level vertical surface before measurements were taken on each participant and after any handling of the inclinometer to ensure an accurate zero starting point. A General Electric LOGIQ™ diagnostic ultrasound (GE Healthcare, Wauwatosa, WI) with 12 MHz linear - multi frequency linear array probe was utilized to perform all measurements of HT. The following parameters were utilized during all ultrasound procedures; frame rate of 35 cycles per second, coded harmonic imaging to reduce noise and enhance true signal, gain of 45, speckle reduction algorithm/frame averaging (S/A) of 3/2, B-mode, depth of
field was 3.5 cm (this was adjusted on two participants due to increased thickness of soft tissue), and a dynamic range of 72.

PROCEDURES

Study participants were seen twice, once during an initial data collection period and again three to five days later, with an average of four days, to have reliability components repeated for HT and BFA. Although there would be no activities in between the initial and follow up data collection period that would influence HT, all participants were asked to avoid any overhead upper extremity resistance training as well as participation in overhead sport activities. This was done to eliminate any potential for increased shoulder musculature tightness or soreness that, although unlikely, may influence the measurements.

All ROM measurement procedures were performed by the primary researcher with a clinical background in musculoskeletal orthopedics and over 10 years of experience. The protocols for each ROM measurements were adapted from published measurement protocols demonstrating good reliability when utilized by the primary researcher of this study. During all ROM measurement procedures, CS placed the digital inclinometer in the appropriate locations when instructed to by the primary researcher. Both the primary researcher and the CS were blinded to the measurement recording by having a cover placed over the digital read out on the inclinometer. Following each measurement, CS would hand the digital inclinometer to a third investigator that removed the cover, recorded the measurement and then zeroed out the inclinometer before replacing the cover and returning to CS.

Measurements of HT were performed by the primary researcher who additionally has over four years of experience utilizing diagnostic ultrasound for research purposes surrounding the shoulder. The primary researcher was blinded to the angle of rotation of the forearm utilizing a visual barrier and blinded to the measurement taken via the digital inclinometer by CS in the same manner as described above to ensure both were blinded.

All BFA measurements were performed by CS who was blinded to the angle of rotation of the forearm utilizing a visual barrier. CS was also blinded to the measurement taken via the digital inclinometer by the primary researcher in the same manner as described initially in order to ensure that both CS and the primary researcher were blinded to the results. All measurements were performed on both upper extremities.

HUMERAL TORSION MEASUREMENT WITH DIAGNOSTIC ULTRASOUND

The participant was positioned in supine with the arm abducted to 90 degrees, neutral rotation of the glenohumeral joint, elbow flexed to 90 degrees, and the forearm and wrist in a neutral position. A folded towel was placed under the humerus until it was visually level with the acromion to create a neutral position along the horizontal plane. Ultrasound gel was utilized as a conductor between the skin and the linear probe. A horizontal line was placed on the viewing screen diagnostic ultrasound, utilizing the measurement function, prior to initializing each imaging study. The probe was then placed at the proximal humerus perpendicular to the shaft of the humerus in order to visualize the greater and lesser tubercles. The probe was moved proximally and distally until the apex of the greater and lesser tubercle were thought to be visualized. Additionally, a small bubble level was placed on the probe to allow for a more consistent angle to be maintained during the procedure. The forearm of the participant was utilized to move the glenohumeral joint into IR and ER passively until the apexes of the tubercles were in line with the horizontal line created on the viewing screen (Figure 1). At this time CS placed the digital inclinometer along the distal anterior forearm to record the measurement (Figure 2).
Table 1. Intrarater reliability measurements

<table>
<thead>
<tr>
<th>Method</th>
<th>Measurement 1 mean angle°(SD)</th>
<th>Measurement 2 mean angle°(SD)</th>
<th>ICC 3,k (95% CI)</th>
<th>SEM°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnostic ultrasound</td>
<td>19.10 (11.74)</td>
<td>18.89 (12.46)</td>
<td>0.923(0.88-0.95)</td>
<td>3</td>
</tr>
<tr>
<td>Biceps forearm angle</td>
<td>20.28 (12.03)</td>
<td>21.40 (11.94)</td>
<td>0.849(0.76-0.91)</td>
<td>5</td>
</tr>
</tbody>
</table>

**BICEPS FOREARM ANGLE WITH PALPATION**

The participant was positioned in supine with the arm abducted to 45 degrees, CS palpated the proximal humerus to place the greater and lesser tubercles underneath one thumb. Maintaining the position of the greater and lesser tubercles under CS’s thumb, the participant’s arm was passively abducted to 90 degrees, with neutral rotation of the glenohumeral joint, the elbow flexed to 90 degrees, and the forearm and wrist in a neutral position. A folded towel was placed under the humerus until it was visually level with the acromion to create a neutral position parallel to the floor. The forearm of the participant was utilized to move the glenohumeral joint into IR and ER passively until the apexes of the tubercles were equally palpable under the thumb and thought to be along the horizontal plane. At this time, the primary researcher placed the digital inclinometer along the distal anterior forearm to record the measurement (Figure 3).

**DATA ANALYSIS**

Collected data were transferred to the Macintosh version of SPSS Statistics Version 23.0 for analysis. Descriptive data including mean measurement angles with SD were calculated for each series of measurements. The intrasession reliability of HT was calculated utilizing the intraclass correlation coefficient (ICC) model 3, k. The mean value of each series of measurements was utilized for the analysis. Model 3, k was used for the intrarater analysis to determine if this particular instrument can be used repeatedly with confidence by the same clinician. Our interpretation of the ICC values were based on guidelines offered by Portney and Watkins,38 whereby a value of above 0.75 was classified as good and a value of 0.50 to 0.75 would be considered to have moderate to poor reliability. The standard error of measurement (SEM) is not affected by intersubject variability and is important for clinical utilization of a measurement procedure; therefore, it will be reported in conjunction with the ICC’s using the formula: SEM = SD with a 68% confidence interval and the ICC (3,k) = r. Pearson product-moment coefficient of correlation (r) using a significance level of p = 0.01 was used for the analysis for the construct validity component of the investigation. Finally, a Bland Altman plot was utilized to calculate the mean difference between measurements as well as evaluate the 95% limits of agreement.

**RESULTS**

**RELIABILITY**

The data analysis of measurements revealed good intrarater reliability of both the HT measurement via diagnostic ultrasound (ICC = 0.923) and the measurements of BFA via palpation (ICC = 0.849). Table 1 contains the mean angular measurements, SD, ICC (95% CI), and SEM.

**VALIDITY**

Convergent validity between HT, as measured via diagnostic ultrasound, and BFA, measured via palpation, was supported by a statistically significant moderate correlation (r = 0.566), (p = <0.001). Table 2 contains the mean, SD, and average values for both HT and BFA.

The 95% limits of agreement between the two measurement methods were -24.80° and 19.80° with a mean difference of -2.50° (SD 11.38), the negative values are present because HT be either have either a positive or negative value (Figure 4).

**DISCUSSION**

The purpose of this investigation was to evaluate interrater reliability and validity of a proposed method for quantifying...
HT that does not require costly imaging modalities and extensive training. Prior to the proposed method put forward by Dashottar and Borstad,\textsuperscript{34} methods utilized to quantify humeral torsion involved CT, magnetic resonance imaging (MRI), and most recently, diagnostic ultrasound. These methods, although extremely accurate, require equipment that is not readily available to a majority of clinicians looking to quantify HT as part of a comprehensive examination of an overhead athlete. Therefore, the proposed method for quantifying HT via palpation seeks to allow an alternative in the absence of the aforementioned equipment. Conceptually, the palpation method is very similar in nature to that of the method utilizing diagnostic ultrasound. In both instances it is necessary to line up the apex of the greater and lesser tubercles on the horizon and then measure the angle of the forearm in this position in order to determine the amount of torsion present in the humerus. The precision to which the diagnostic ultrasound would be able to identify the greater and lesser tubercles would appear to be much improved, in comparison to palpation, given the ability to penetrate varying depths of the overlying soft tissue and very clearly visualize these osseous landmarks. Furthermore, utilizing the measurement feature on the diagnostic ultrasound machine, it is possible to create a true horizontal line on the screen in order to line up the apex of the tubercles once identified.

Despite the aforementioned differences, the validity results from the original study by Dashottar and Borstad\textsuperscript{34} demonstrated a correlation ($r = 0.85$) between diagnostic ultrasound measurements and measurements through palpation among 49 shoulders. However, clinical measurements based on palpating the arm in 45 and 90 degrees of abduction as well as horizontal adduction have been proposed in another study that reportedly lack validity when compared to diagnostic ultrasound ($r \leq 0.326$).\textsuperscript{35}

The results of the correlation analysis from previous studies\textsuperscript{34,35} differ from those reported in the current investigation ($r = 0.566$), however, given the contrasting reports from previous studies, further investigation was warranted. There are several possible reasons for these differences which require consideration prior to proposing the method of palpation as a reasonable alternative for quantifying HT as opposed to current diagnostic ultrasound or other imaging studies. First, the palpation methods utilized in each study differed. The original study by Dashottar and Borstad\textsuperscript{34} performed the palpation method with the arm directly at the side in order to better palpate the tubercles as there is less soft tissue directly over the tubercles in this position. In the study by Feuerherd et al\textsuperscript{35} the palpation was performed and measured with the arm directly positioned in 45 degrees of abduction as well as in 90 degrees of abduction. The method utilized in the current study placed the arm in 45 degrees of abduction to palpate the tubercles and then moved the arm into 90 degrees of abduction while maintaining the palpated position. This method was performed to initially accommodate for less soft tissue being over the tubercles and then moved into the position in which the diagnostic ultrasound measurement was performed in order to remain consistent with both measurement positions. It is unclear from the methods section in the original study what position the arm was in when the ultrasound measurement was taken. Secondly, the experience and training of the individuals taking the measurements, both utilizing the diagnostic ultrasound and palpation method, may have also been different. From the original study\textsuperscript{34} it is noted that the individual performing the ultrasound measurements spent three months familiarizing themselves with the ultrasound unit and identifying anatomical structures of the shoulder which was further refined by a pilot study of 20 shoulders. In the current study, the researcher performing the ultrasound measurements had four years of experience utilizing diagnostic ultrasound for research regarding the shoulder while the researcher performing the palpation method had very little experience. The previous study\textsuperscript{34} indicates that the same individual performed both the diagnostic ultrasound measurements as well as the palpation measurements. It is possible that experience with palpation, particularly the palpation method proposed in both studies, may influence the results, much like is seen with experience surrounding diagnostic ultrasound methods.

**Table 2. Convergent validity between humeral torsion measurements via diagnostic ultrasound and biceps forearm angle**

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean angle$^\circ$ (SD)</th>
<th>Range$^\circ$</th>
<th>Minimum$^\circ$</th>
<th>Maximum$^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnostic ultrasound</td>
<td>18.89 (12.46)</td>
<td>75.97</td>
<td>1.00</td>
<td>76.97</td>
</tr>
<tr>
<td>Biceps forearm angle</td>
<td>21.40 (11.94)</td>
<td>56.50</td>
<td>1.00</td>
<td>57.50</td>
</tr>
</tbody>
</table>

**Figure 4.** Bland-Altman plot indicating differences between palpation and ultrasound measurements of humeral torsion
The results of the current study demonstrate that both the method utilizing diagnostic ultrasound and palpation for quantifying HT exhibit good intrarater reliability, ICC = 0.923 and ICC = 0.849 respectively. However, the SEM differs slightly between the diagnostic ultrasound and palpation methods, 3° and 5° respectively meaning that the measurement obtained via diagnostic ultrasound may be 3° more or less than the true measurement and slightly greater, 5° when considering the palpation method. The previous study reported an SEM value that were slightly lower than the current study, 3° for the palpation method, but are very close to the value calculated for the diagnostic ultrasound method. A higher SEM for the palpation methods in this study could indicate a greater variability in measurements due to a larger standard deviation, leading to a greater probability of measurement error. Furthermore, a recent study by Yaari et al that quantified HT in baseball pitchers concluded that the palpation method significantly underestimated the amount of humeral torsion when compared to diagnostic US and that these methods should not be utilized interchangeably.

Lastly, the overall mean difference between measurement methods in the current study was -2.50° (SD 11.38) which appears to be relatively low and indicates that HT was on average 2.5° lower for the diagnostic ultrasound. However, the range between the 95% limits of agreement (-24.80° and 19.80°) is relatively large. These results indicate that it is possible to either overestimate or underestimate the HT angle by a range of at least 19.8°, which suggests the need for caution if using the two measurement methods interchangeably. These results differ greatly from the study by Dashottar and Borstad which reported 95% limits of agreement between -8.3° and 7.9°, which indicate that the palpation method could either overestimate or underestimate the measurement by approximately 8°. The mean difference in the referenced study was -0.2° (SD 4.1°). Dashottar and Borstad proposed the reason for their values with greater error may be a result of the anatomy of the lesser tubercle, more specifically when its angle relative to the bicipital groove is lower, not being as sensitive to palpation. This reason may also be speculated to have some influence on the results of the current study but do not account for such a wide range. The authors of the current study believe the possible explanations for this wide range of error may lie in both the palpation method and experience of the one performing it, as mentioned earlier in the discussion.

Although both methods demonstrate the ability to be reproduced among the same rater with some consistency, the question surrounding the validity of the palpation method when compared to the diagnostic ultrasound method still remains. It is possible that overall experience with palpation and, particularly, experience with the BFA may contribute to the overall ability of an individual to quantify HT via palpation. This variable, along with intrarater reliability, will be important to investigate prior to determining if this method is a practical alternative to measuring HT via diagnostic ultrasound as student clinicians and residents are likely to employ this method.

LIMITATIONS

There are several possible limitations that influence the overall results and interpretation of the findings of this current study. First, the convenience sample utilized for this study was a healthy college aged population and although it consisted of many overhead athletes or former athletes, it may not be representative of the overall population of interest. The authors did not include an investigation of interrater reliability for either measurement and therefore the overall clinical utility of the methods investigated is not fully understood. Furthermore, the training of the individuals for both measurements may also be seen as a limitation of this study. Although the student was trained on the use of the BFA measurement by the principal investigator, she had limited experience with this technique prior to beginning this study. Future studies should seek to determine if training experience with the method utilizing palpation influences convergent validity as well as investigating interrater reliability.

CONCLUSION

The palpation method for quantifying HT appears to demonstrate a good degree of intrarater reliability among an asymptomatic population. Of concern is the lack of concurrent validity when compared to diagnostic ultrasound. Although the palpation method for quantifying HT lacks validity when compared to diagnostic ultrasound, it may be a plausible alternative to quantifying HT when other methods are not available. Specifically, in cases where costly imaging modalities are not available, the palpation method may be useful for side-to-side comparisons of HT. Having some understanding of side-to-side differences allows the clinician to have an understanding of the underlying etiology of shoulder stiffness in both non-operative and post-operative populations. Further investigation is warranted to determine the influence of experience among those performing the measurement and the position of the glenohumeral joint during palpation. Although the use of asymptomatic participants may limit generalization, the use of symptomatic participants is unlikely to confound the results as most are able to achieve the needed passive range required for testing.

CONFLICTS OF INTERESTS

The authors report no conflicts of interest.

FUNDING

The authors received no funding for any portion of this study.

ETHICAL APPROVAL

Institutional Review Board Approval through the University of Indianapolis #906

International Journal of Sports Physical Therapy
REFERENCES


Background

The OnBaseU screen was developed to evaluate a baseball pitcher’s ability to perform movement patterns key to pitching. However, due to lack of validation, it is unclear what application is ideal for this screen.

Purpose

To compare four OnBaseU tests to relevant pitching mechanics measured using 3D motion capture to evaluate if the OnBaseU screen can be used to assess pitching mechanics. The secondary purpose was to compare OnBaseU and 3D motion capture seated trunk rotation test results to determine the validity of the OnBaseU test.

Methods

OnBaseU screening and 3D motion capture pitching evaluations were completed for 103 adolescent pitchers (age = 15.2 ± 1.29 years; height = 1.80 ± 0.0866 m; weight = 76.2 ± 13.8 kg). A motion capture seated trunk rotation test was also conducted on 80 of the 103 youth players (age = 15.2 ± 1.32 years; height = 1.80 ± 0.0889 m; weight = 75.7 ± 13.9 kg).

Results

Stride length and OnBaseU side step walkout test data were moderately correlated, and all other comparisons were not correlated or were minorly correlated. No significant differences were found between kinematics from players who obtained different OnBaseU scores, except for stride lengths during pitching of players who scored a 1 or 3 on the OnBaseU side step walkout test (p<0.01). Further, OnBaseU and motion capture seated trunk rotation tests were not correlated (r = 0.003) and not found to be statistically associated (p = 0.83).

Conclusion

Results from this study indicate that the OnBaseU clinical assessment screen may not have use in assessing pitching mechanics and that visual grading criteria used in the OnBaseU seated trunk rotation test may not be accurate.

Level of Evidence

3

INTRODUCTION

Despite increased knowledge regarding pitching mechanics and the implementation of pitch count limitations, the incidence of injury among youth baseball pitchers is still on the rise.

Improper pitching mechanics has been identified to play a large role in injury risk. Increased elbow valgus torque, decreased shoulder rotational range of mo-
tion, knee flexion at front foot contact, and early rotation of the hips and shoulders have all been found to correlate with increased risk of injury for baseball pitchers. \textsuperscript{4–6} Evaluation of pitching mechanics is integral for injury prevention as well as for performance improvement.

The existing gold standard for pitching performance and injury prevention analysis is evaluation with a 3D motion capture system. However, most athletes do not have access to these systems due to their cost, limited availability, and the need for a team biomechanist to operate the system, process data, and assist with interpretation of findings. Validated clinical movement screens have previously been utilized to estimate an athlete’s risk of injury as well as their overall performance. The Golf Movement Screen (GMS) evaluates a golfer’s movement ability in 10 different exercises. Through biomechanical analysis using an electromagnetic tracking system, the GMS has been shown to correlate with important aspects of golf swing mechanics, such as spine control and increased separation between the upper torso and pelvis rotation.\textsuperscript{7} The Functional Movement Screen (FMS\textsuperscript{TM}) is a widely used measurement of movement ability that has also been shown to be predictive of musculoskeletal injury.\textsuperscript{8,9} The FMS\textsuperscript{TM} measures dynamic balance, strength, and flexibility,\textsuperscript{10} and a lower FMS\textsuperscript{TM} score suggests improper fundamental movement patterns, and increased injury risk.\textsuperscript{11} This concept has been validated in multiple studies assessing the correlation between FMS\textsuperscript{TM} score and serious injury.\textsuperscript{8,12,13}

The OnBaseU screen is a clinical assessment tool developed by a team of baseball and softball coaching, strength and conditioning, biomechanics, and medical experts. OnBaseU University\textsuperscript{©} is a for-profit organization that requires a certification course to administer the screening assessment. No educational requirements are necessary to obtain certification. Developers state that the screen is meant to assess the movement patterns of baseball and softball pitchers and hitters through 16 movement tests.\textsuperscript{14} Any rationale for or validity of each component of the movement screen have yet to be published or made available through materials obtained by taking the certification course. This assessment tool is marketed to coaches, strength and conditioning experts, athletic trainers, and physical therapists as a low-cost and portable clinical screen that could help identify and track progress of specific movement patterns that are key to achieving efficient pitching mechanics.\textsuperscript{14} However, it is unclear how this assessment tool can be used most appropriately because no studies regarding reliability of this screen exists. It has also yet to be studied if this screening tool has value in predicting injury risk or potentially injurious or inefficient pitching mechanics. Further, it is unknown if this screen should be used in place of or in conjunction with a pitching 3D motion analysis. The primary purpose of this study was to compare screen results from four OnBaseU tests to relevant pitching mechanics measured using 3D motion capture to evaluate if the OnBaseU screen can be used to assess pitching mechanics. The secondary purpose was to compare OnBaseU and 3D motion capture seated trunk rotation test results to determine the validity of the OnBaseU test. The authors hypothesized that OnBaseU tests would be associated with analogous pitching mechanics. The authors additionally hypothesized that On-BaseU seated trunk rotation test results would be associated with 3D motion capture seated trunk rotation test results. The results of this study can be used to assess whether portions of the OnBaseU clinical movement screen analyzed in this study can be used to estimate corresponding pitching mechanics.

### METHODOLOGY

#### DATA COLLECTION

One hundred and three adolescent pitchers (age = 15.2 ± 1.29 years) completed the OnBaseU screening assessment and a 3D motion analysis of pitching. Participant demographics can be seen in Table 1. Participant inclusion criteria included youth baseball players ranging from ages 13 to 20 years who declared pitching as their primary position. No data were collected from players who were experiencing pain and player data were not included in this analysis if that participant did not complete both the OnBaseU screening and motion capture evaluation. After OnBaseU screening was completed, players were instructed to conduct a normal pre-game warmup prior to motion capture analysis. A motion capture seated trunk rotation test was also conducted on 80 of the 103 youth players (age = 15.2 ± 1.52 years; height = 1.80 ± 0.0889 m; weight = 75.7 ± 13.9 kg). OnBaseU screening was performed by a strength and conditioning coach with over 12 years of experience who is certified by the College of Strength and Conditioning Coaches association (CSCCa) and OnBase University\textsuperscript{©}. Motion capture evaluations were conducted by a biomechanist who holds a doctorate degree with a research focus in motion capture biomechanics and sports medicine.

#### ONBASEU DATA COLLECTION

The screen consists of 16 consecutive tests intended to identify patterns in a player’s pitching mechanics. For this study, four OnBaseU tests were selected for comparison by the strength and conditioning coach and biomechanist based on the face validity for what tests would be most directly associated with 3D motion capture metrics. These four tests were: (1) seated trunk rotation test, (2) side step walkout test, (3) push-off test, and (4) shoulder 90/90 test. The other 12 tests that are a part of the screening assessment are not analogous to pitching metrics and, therefore, were not included in comparisons for this study. Screening

<table>
<thead>
<tr>
<th>Participant Ages</th>
<th>Number of Participants</th>
<th>Height (m; mean ± SD)</th>
<th>Weight (kg; mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 years</td>
<td>n = 10</td>
<td>1.69 ± 0.10</td>
<td>57.43 ± 9.17</td>
</tr>
<tr>
<td>14 years</td>
<td>n = 27</td>
<td>1.78 ± 0.09</td>
<td>73.04 ± 15.17</td>
</tr>
<tr>
<td>15 years</td>
<td>n = 18</td>
<td>1.78 ± 0.06</td>
<td>76.15 ± 7.73</td>
</tr>
<tr>
<td>16 years</td>
<td>n = 32</td>
<td>1.84 ± 0.06</td>
<td>80.82 ± 9.85</td>
</tr>
<tr>
<td>17 years</td>
<td>n = 12</td>
<td>1.87 ± 0.08</td>
<td>88.34 ± 13.79</td>
</tr>
<tr>
<td>18 years</td>
<td>n = 3</td>
<td>1.81 ± 0.04</td>
<td>72.73 ± 4.91</td>
</tr>
<tr>
<td>All</td>
<td>n = 103</td>
<td>1.80 ± 0.09</td>
<td>76.16 ± 13.81</td>
</tr>
</tbody>
</table>

Table 1. Study Participant Demographics

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was conducted in accordance with OnBaseU methods. The screen was terminated if the participant communicated experiencing pain at any point during testing. Descriptions for how to conduct each of the four tests included in this study are detailed below.

A seated trunk rotation test has been described previously and has demonstrated inter-tester and intra-tester reliability when measured with a goniometer in healthy adults. OnBaseU adapted this test to include a cervical spine component and is measured using visual assessment, rather than a goniometer or other measurement device. The seated trunk rotation test (Figure 1A) measures cervico-thoraco-lumbar spine mobility, which is postulated by OnBaseU to be associated with upper and lower body separation during a pitch. The test consists of two parts. First, the player is instructed to sit holding a bat across their shoulders, with their right foot crossed over the left. The player is then instructed to rotate their thorax to the right as far as possible without rotating the pelvis. OnBaseU grading criteria consists of a visual assessment of having completed a trunk rotation angle that is "greater than 45°", "equal to 45°", or "less than 45°". Second, the player is instructed to turn their head back to the left as far as possible while maintaining this rotated position. The player is evaluated according to OnBaseU grading criteria, which is a visual assessment of if they had turned their chin "over the clavicle" or "short of the clavicle". Both parts of the test are then performed and evaluated for the contralateral side.

The side step walkout test (Figure 2A) was developed by OnBaseU with the intention of identifying how hip and groin flexibility influences the player’s ability to stride effectively during a pitch. To conduct this test, the player is first instructed to lay on the ground. Two baseballs are placed outside the foot and ipsilateral shoulder to serve as markers for the test. Next, the player is instructed to stand up, stand in-line with one baseball, and stride with the opposite foot as far as possible without losing balance. This is done for both left and right sides. OnBaseU criteria for evaluation consists of a visual assessment of whether the stride foot was "past the ball", "equal to the ball" or "less than the ball".

The push-off test (Figure 3A) was developed by OnBaseU in an effort to measure hip and groin flexibility during a stride motion, but it also combines these measures with lower body motor control evaluation. This test consists of two parts. First, the player is instructed to stride out as far as possible such that the striding foot lands perpendicular to the standing foot, similar to a stride performed when pitching. The distance of the stride is measured by the player’s foot lengths. Foot length measurements, as defined by OnBaseU, measure distance as the number of lengths of the participants feet. This measurement is obtained by having the participant walk placing their heel against the contralateral toe and counting how many foot lengths were needed to cross the distance being measured. To the authors knowledge, this method of measuring distance has not been validated. OnBaseU grading criteria consists of a visual assessment of whether the distance between feet is "greater than 6 foot lengths", "5-6 foot lengths", or "less than 5 foot lengths". The second part of this test is conducted the same as the first, but in the second part the player is instructed to drive off the standing leg and allow that foot to drag as they would in a normal pitch. OnBaseU evaluation for this part consists of a visual assessment of if the additional distance between the feet was "greater than 1 foot length", "0.5-1 foot lengths", or "less than 0.5 foot lengths" of additional distance from part 1. This was done for both left and right sides.

The shoulder 90/90 test (Figure 4A) was previously developed and was included in this screen with the intention of testing gleno-humeral joint mobility and scapulo-thoracic
stability, according to OnBaseU. For this test, the player is instructed to stand with slight hip and knee flexion and hold the arm out with 90° elbow flexion and 90° shoulder abduction. In this position, the player is then told to externally rotate at the shoulder joint as far as possible without spinal extension. This is performed and evaluated for both arms. OnBaseU grading criteria evaluates movement by visually assessing if the forearm long-axis rotation about the shoulder joint was "greater than the spinal angle", "equal to the spinal angle", or "less than the spinal angle".

MOTION CAPTURE DATA COLLECTION

Motion capture data were collected at 250 Hz using the 40 reflective marker set required for PitchTrak (Motion Analysis Corporation, Santa Rosa, California) and a twelve-camera motion analysis system (Qualisys AB, Göteborg, Sweden). The mound was engineered to meet major league specification, and pitches were thrown to a catcher located at major league regulation distance. Participants conducted a normal pre-game warmup, followed by pitching four fastballs, four changeups, and four breaking balls. Reports of kinetic and kinematic data were generated using Visual3D (C-Motion, Inc, Germantown, MD) and the Qualisys Baseball PAF (Qualisys AB, Göteborg, Sweden). Only data from fastballs were included in this study. These metrics were hip shoulder separation at foot strike (°) (Figure 1B), stride length (%body-height) (Figure 2B and 3B), and shoulder maximum external rotation (°) (Figure 4B). Hip shoulder separation at foot strike is the angle between the axis created by the left and right acromion markers and the axis created by the left and right anterior superior iliac spine markers. Shoulder external rotation is the rotation about the long-axis of the humerus.

In addition to metrics calculated from pitching evaluations, trunk rotation during a seated trunk rotation test was measured using the motion capture system. Players were instructed to sit with their arms crossed across their chest such that their hands were placed on their shoulders and a soccer ball was placed between their knees. They were then told to rotate their thorax as far as possible without rotating the pelvis. Trunk rotation was the angle between the axis created from the right and left shoulder acromion markers and the axis created from the right and left anterior superior iliac spine.

STATISTICAL ANALYSES

Only OnBaseU screen data from the throwing side were included in this study as these data were relevant for comparison with pitching biomechanics 3D motion capture data. For quantitative analysis in this study, OnBaseU scoring categories were converted to point values. This was done for the two-part tests to be condensed into one score that could be used for statistical analysis. Tests that only contained one part were also converted to point values for consistency. Points were assigned to the evaluations where the best to worst test performance was awarded the greatest to least number of points. For part one of the OnBaseU seated trunk rotation test, evaluations of "greater than 45°" were assigned three points, "equal to 45°" were assigned two points, and "less than 45°" were assigned one point. For part two of this test, evaluations of "over the clavicle" were assigned two points and "short of the clavicle" were assigned one point. Points from the two parts were combined to create one test grade ranging from 2-5. For the side-step walkout test data, evaluations of "past the ball" were assigned a test grade of 3, "equal to the ball" were assigned a grade of 2, and "less than the ball" were assigned a grade of 1. For part one of the push-off test, evaluations of ">6 foot lengths" were assigned three points, "5-6 foot lengths" were assigned two points, and "<5 foot lengths" were assigned one point. For the second part of this test, evaluations of ">1 foot length gain" were assigned three points, "0.5-1 foot length gain" were assigned two points, and "<0.5 foot length gain" were assigned one point. Points from both parts of the test were combined to create one test grade ranging from 2-6. For the shoulder 90/90 test, evaluations of "greater than spinal angle" were assigned a test grade of 3, "equal to spinal angle" were assigned a test grade of 2, and "less than spinal angle" were a grade of 1.

Correlation coefficients and corresponding p-values and 95% confidence intervals were calculated to determine if OnBaseU tests were associated with pitching mechanics that were hypothesized to be related. Correlation coefficients of r < 0.1, 0.1 ≤ r < 0.3, 0.3 ≤ r < 0.5, and r ≥ 0.5 were defined as not correlated, minorly correlated, moderately correlated and highly correlated, which is in accordance with Cohen’s definition. Additionally, average pitching mechanics from different OnBaseU scoring categories were compared to understand if OnBaseU scoring criteria possessed precision such that different scoring categories result in different mechanics. If statistical differences were not found between groups, this would indicate that players with similar pitching mechanics could obtain different scores on the OnBaseU test, and that scoring criteria as it is currently defined is potentially not useful. Visual inspection of the box and whisker plots of the four comparisons showed that the data were not normally distributed. Therefore, a non-parametric Kruskall-Wall test with a Chi-squared approximation was performed using JMP (JMP, Cary, NC) to test if there were differences between averages of any groups. If the two-
etailed p-value from the Kruskall-Wallis test was significant (p<0.05), a Dunn’s post-hoc test was used to assess which pairwise comparisons might be significant. A Common Language Effect Size (CLES) and 95% confidence interval (CI) for that effect size was reported for each comparison that yielded a statistically significant p-value from the Dunn’s post-hoc test. The CLES modifies the $d_{cohen}$ effect size by calculating the pooled standard deviation with weights to account for groups with different sample sizes.

RESULTS

Motion capture metrics and OnBaseU screen results from 103 adolescent baseball pitchers were compared. Figure 5A-D shows comparisons between motion capture metrics (y-axis) and the OnBaseU tests (x-axis) that were hypothesized to be associated (to discern face validity).

Hip shoulder separation at foot strike (°) and OnBaseU seated trunk rotation test data (Figure 5A) were minorly correlated ($r = 0.19$; p = 0.05; 95% CI = -0.005 - 0.57). Different OnBaseU seated trunk rotation test grades did not correspond to statistically significantly different hip shoulder separation at foot strike angles (°) from the motion capture system (p = 0.18).

Stride length during pitching (%body-height) and OnBaseU side step walkout test data (Figure 5B) were moderately correlated ($r = 0.34$; p = 0.0003; 95% CI = 0.16 - 0.50). Stride lengths (% body-height) from the motion capture system of players who obtained OnBaseU side step walkout test grades of 1 vs. 3 were statistically significantly different (p < 0.01; CLES = 0.735; CI = 0.395 - 1.378). Comparisons of all other groups in this dataset were not significantly different.

Stride length (% body-height) during pitching and OnBaseU push-off test data (Figure 5C) were not correlated ($r = 0.18$; p = 0.06; 95% CI = -0.01 - 0.36). Different OnBaseU push-off test scores did not correspond to statistically significantly different stride length data (% body-height) from the motion capture system (p = 0.07).

Shoulder maximum external rotation (°) and the shoulder 90/90 test data (Figure 5D) were not correlated ($r = 0.13$; p = 0.18; 95% CI = -0.06 - 0.32). Different OnBaseU shoulder 90/90 scores did not correspond to statistically significantly different shoulder maximum external rotation data (°) from the motion capture system (p = 0.10).

OnBaseU and motion capture seated trunk rotation test data (Figure 6) were not correlated ($r = 0.005$; p = 0.98; 95% CI = -0.22 - 0.22). OnBaseU seated trunk rotation scores did not correspond to motion capture seated trunk rotation test data (p = 0.85).

DISCUSSION

The hypothesis that OnBaseU tests would be associated with analogous pitching mechanics was not supported by the results of this study. The four comparisons between pitching mechanics and OnBaseU tests analyzed in this report had an overall positive trend (Figure 5A-D). Only stride length (%body-height) during pitching and the side step walkout test results were moderately correlated, while all other comparisons between OnBaseU tests and pitching mechanics were either minorly correlated or not correlated. Further, only the stride length (%body-height) of individuals who scored a 1 and 3 in the OnBaseU side step walkout test was statistically significantly different (p<0.01). Contrary to the secondary hypothesis, OnBaseU seated trunk rotation test data and the motion capture seated trunk rota-
tion test data were not correlated, calling into question the validity of the visual scoring method and evaluation criteria in the OnBaseU screen (Figure 6). While most OnBaseU tests were not found to be associated with 3D motion capture pitching mechanics examined in this study, they may have value when used in other contexts to identify areas of deficiency that may lead to improper mechanics. Further study is required to understand how this movement screen can be used.

In the OnBaseU literature, the seated trunk rotation test adapted by OnBaseU is described as a measurement of trunk axial flexibility. According to Senington et al., hip–shoulder separation is an accurate measurement of trunk axial flexibility, particularly lateral flexion, making it a reasonable comparison to the OnBaseU seated trunk rotation screen. However, hip shoulder separation during throwing is a dynamic movement that is affected by not only flexibility, but also strength, timing, and skill. The OnBaseU seated trunk rotation test was unable to estimate hip shoulder separation at foot strike, but if used in combination with a motion capture evaluation, it could potentially inform regarding why a pitcher may demonstrate poor hip shoulder separation by either identifying or eliminating axial flexibility as a cause.

The OnBaseU seated trunk rotation test score results were also compared to a seated trunk rotation test measured using motion capture. OnBaseU seated trunk rotation test grades did not demonstrate statistically significant differences when compared with motion capture seated trunk rotation results. OnBaseU scoring criteria may lack the precision to distinguish between trunk rotation abilities through visual analysis by the evaluator. This calls into question the validity of the scoring criteria and if it is defined in a way that the test can be conducted with accuracy. Seated trunk rotation angle was an average of 62.8° ± 10.1° for all 80 pitchers. This is comparable to previous work that reported an average seated trunk rotation angle of 69.9° ± 9.8° in 21 non-injured collegiate baseball players. The side step walk out test is described by OnBaseU as a measurement of hip and groin flexibility, and since stride length during a pitch has been shown to be associated with bilateral total arc of adduction and abduction of the hips, these two measurements were compared. Those who scored a 1 and 3 on the OnBaseU side step walkout test had statistically significantly different stride lengths during pitching (p < 0.01). This test may, therefore, have value in predicting stride length. When used in conjunction with motion analysis, the side step walkout test could potentially inform whether hip and groin flexibility is either too low or high in players with undesirable stride lengths, thereby aiding coaches and athletic trainers in developing a program for that player. A comparison of passive hip range of motion and the side step walkout test is needed to further validate this test.

In addition to the side step walkout test, OnBaseU uses the push-off test to evaluate hip and groin flexibility during a stride motion as well. Therefore, these test results were also compared to stride length during pitching measured using 3D motion capture. The push-off test was not associated with stride length. The recommended stride length is approximately 80–90% of body-height in adult pitchers. Smaller stride lengths of approximately 50% body-height have been shown to increase throwing arm momentum, potentially increasing injury risk in adults. In youth athletes, every 10% increase in stride length has been found to be correlated with a 1.9 ± 0.4 mile per hour pitch velocity increase. Larger stride lengths alter timing of stride foot contact, shortening double support phase of the pitch. This may result in loss of momentum transferred through the kinematic chain. However, larger stride lengths of up to 100% body-height are sometimes beneficial and have been found to be associated with increased ball velocity. In the current study, most pitchers had stride lengths within the recommended range and the sample size of players who scored a 5 or 6 was very low (n=0–4). This raises the question of whether the higher 5 or 6 test scores are achievable, would be considered over-striding, and whether this stride length would be advantageous for that player.

The shoulder 90/90 test was adapted by OnBaseU to highlight any limitations in glenohumeral joint range of motion and/or stability of the scapula-thoracic junction. This test was compared to maximum external rotation of the throwing shoulder during the late cocking phase of a pitch measured using 3D motion capture as this metric has been shown to represent gleno-humeral joint mobility as well as scapular and thoracic movements during a pitch. The shoulder 90/90 test scores of 2 and 3 were not associated with maximum shoulder external rotation angles obtained using motion capture during pitching. However, if used in conjunction with motion analysis, the OnBaseU test may inform whether flexibility is the reason for disadvantageous maximum external rotation.

A potential reason for the lack of association between OnBaseU tests and pitching mechanics is that OnBaseU is a series of movement tests that are performed prior to warmup. Warmup is a key aspect of athletic performance that has been shown to increase flexibility, providing benefits such as improved joint range of motion as well as enhanced muscular performance. Therefore, since OnBaseU screens are performed prior to warmup, these aspects of the pitching motion may vary from when they are evaluated by the motion capture system post-warmup. Additionally, most OnBaseU tests are static and isolate a single area of...
interest to be measured. Though this may be effective for identifying specific physical limitations, it does not accurately simulate the dynamic and complex pitching motion. Also, many OnBaseU tests measure an athlete’s active range of motion, rather than the dynamic measurements that are displayed during a real-time pitching motion. In throwing athletes, dynamic range of external shoulder rotation is significantly higher than active or passive range of motion measurements due to active muscle tone so it is reasonable to infer that similar effects may be observed in aspects of the pitching motion as well.

In addition to biomechanical differences between pitching evaluation methods, sample size could have affected this analysis. The side step walkout test was the only OnBaseU test that had enough participants in the two most extreme categories (i.e. test score of 1 vs. test score of 3) to be able to perform a statistical comparison. All other OnBaseU tests lack the sample size in either the lowest or highest test scores (n=0-4) to allow for reasonable comparison of those categories (Figure 5A-D). Given that so few participants achieved these scores out of 103 players, it is unclear if these scores are physiologically relevant or even reasonably achievable. These results call into question how the intermediate scoring categories can be used to assess efficient or deficient movement patterns specific to pitching. It can be seen that intermediate scoring categories lack the precision to be associated with corresponding pitching mechanics. Similarly, the seated trunk rotation test measured using motion capture revealed that the OnBaseU seated trunk rotation test scoring criteria may not defined in a way that can be used correctly. Further study is required to determine what ranges of motion can be visually distinguished from each other for each test and scoring criteria should be adjusted accordingly. Additional study should also include multiple evaluators to exclude the variable of evaluator error. An additional question is whether the OnBaseU seated trunk rotation, push-off and shoulder 90/90 tests lack the highest test score categories can predict corresponding pitching mechanics collected with a motion capture system. If this were found to be the case, however, it must be noted that the predictive value of those two OnBaseU scoring categories would only be in forecasting binary “good” vs. “bad” mechanics.

It is important to acknowledge the limitations of this study. Further analysis is needed to examine predictive potential of the lowest and highest test grades from the OnBaseU seated trunk rotation test, push-off test and shoulder 90/90 tests. Few athletes fell into either the lowest or highest test score categories in these three tests, so comparison of these groups was either not possible or not reasonable. However, given how few players received these scores out of 103 participants, it is unlikely that the addition of more participants would increase the sample size in these scoring categories and may indicate that these scores are not relevant or not reasonably achievable. Another limitation of this study is that each part of a two-part test was weighted equally when combining them in order to create a quantifiable score for analysis. Therefore, if one part of the test was more clinically significant than the other, this was not reflected in the analysis. However, consensus among those trained in the use of the OnBaseU screen is that the two parts combined in this study were of equal clinical significance. The OnBaseU seated trunk rotation test was completed with different methods than the motion capture seated trunk rotation test. The OnBaseU test included a second part to the test that evaluated cervical spine motion while the motion capture test did not. It is possible that the lack of correlation between the OnBaseU and motion capture seated trunk rotation tests is due to the differences in how the tests were conducted. While the age range of 14-20 years included players of varying skill, height and weight, statistical analysis of data obtained from 13-15 year-olds, 16-18 year-olds and 19-20 year-olds found that OnBaseU and motion capture data had no statistically significant relationships. These data were not included in this manuscript as they elicited no additional information beyond data presented here. Finally, it is unclear what the effect of education and experience of the evaluator had on the results of the OnBaseU screen. This study included data produced by only one evaluator so no additional variability from multiple evaluators were introduced. However, prior study of the Selective Functional Movement Screen™ found that experience as an evaluator did affect intra- and inter-rater reliability using a visual and subjective scoring method. Considering that there are no education requirements to obtain certification to administer this screen, evaluators will have varying training and knowledge that could alter reliability of the screen.

CONCLUSION

OnBaseU seated trunk rotation, push-off and shoulder 90/90 tests were found to demonstrate either minor correlations or not be correlated with corresponding 3D motion capture measurements of pitching mechanics. Only the stride length (% body-height) during pitching and side step walkout test data were moderately correlated. Stride lengths (% body-height) of players who scored a 1 or 3 on the OnBaseU side step walkout test groups were statistically significantly different (p<0.01). Therefore, these two side step walkout test scoring categories may be able to provide information about stride length during pitching. Statistically different results between OnBaseU and motion capture measures of the seated trunk rotation tests indicate that the OnBaseU seated trunk rotation test may not accurately evaluate trunk rotation. The results of this study indicate that it may not be appropriate to assess youth pitching mechanics with the OnBaseU clinical assessment screen. Future study comparing OnBaseU results to metrics of movement, pain, and injury are needed to determine the value of this screen.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to disclose.

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Reliability of an Observational Biomechanical Analysis Tool in Adolescent Baseball Pitchers

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Background
Improper pitching mechanics are a risk factor for arm injuries. While 3-dimensional (3D) motion analysis remains the gold standard for evaluation, most pitchers and clinicians do not have access to this costly technology. Recent advances in 2-dimensional (2D) video technology provide acceptable resolution for clinical analysis. However, no systematic assessment tools for pitching analysis exist.

Purpose
To determine the reliability of the Assessment of biomeChanical Efficiency System (ACES) screening tool using 2D video analysis to identify common biomechanical errors in adolescent pitchers.

Study Design
Cross-sectional.

Methods
Adolescent baseball pitchers underwent analysis using 2D video in indoor settings. Observational mechanics were collected using a 20-item scoring tool (ACES) based on 2D video analysis. Fleiss’ kappa, interclass correlation coefficients (ICC), and frequencies were used to examine intra-/interrater reliability based on common pitching errors.

Results
Twenty asymptomatic pitchers ages 12-18 years were included. Total ACES scores ranged from 1 to 13, normally distributed. ACES total score demonstrated excellent intra-rater reliability within each rater (ICC for rater 1 = 0.99 (95% CI: 0.98, 0.99); ICC for rater 2 = 0.94; 95% CI: 0.84, 0.97); ICC for rater 3 = 0.98 (95% CI: 0.96, 0.99). There was excellent interrater reliability across the trials and raters (ICC = 0.91; 95% CI: 0.82, 0.96). The ACES tool demonstrated acceptable kappas for individual items and strong ICC 0.91 (95% CI: 0.82, 0.96) for total scores across the trials. Regarding identification of biomechanical errors, “front side position” was rated erroneous in 84/120 ratings (70%), stride length in 52/120 ratings (43.3%) and lead hip position in 53/120 ratings (44.2%).

Conclusions
The 20-item ACES scoring tool with 2D video analysis demonstrated excellent intra- and interrater reliability when utilized by raters of different musculoskeletal disciplines. Future studies validating 2D vs. 3D methodology are warranted before ACES is widely disseminated and utilized for adolescent pitchers. ACES is a practical and reliable clinical tool.
INTRODUCTION

Upper extremity injuries in youth and adolescent baseball pitchers remain common, ranging from self-limited, growth-related disturbances including Little League Shoulder to career-threatening injuries such as ulnar collateral ligament (UCL) tears.1–8 Risk factors for injury are multifactorial and include overuse, fatigue, player demographics, throwing volume and velocity, improper biomechanics, and kinetic chain imbalances pertaining to strength, range of motion, and flexibility.3,5,9–11 Technological advances in 3-dimensional (3D) motion analysis and high-speed videography in the past few decades have contributed to a better understanding of pitching biomechanics in pitchers of all ages and levels.12,15 While the preponderance of research has focused on the collegiate and professional pitcher, recent investigations of youth and adolescent pitching mechanics have led to a refined comprehension of critical relationships between functional strength, mobility, and stability as they relate to mechanical efficiency, injury risk, and performance.14–18 Despite these technological advances, pitching-related youth and adolescent upper extremity injuries have reached epidemic proportions.3,5,9–11 Ulnar collateral ligament reconstruction (the “Tommy John surgery”) now has a higher incidence in 15 to 19 year-old throwing athletes than any other group, including professional athletes.19

The gold standard for assessing pitching biomechanics in all age groups is 3D motion analysis, which provides valuable quantitative measures of pitching kinetics and kinematics; however, it is costly, time- and resource-intensive, typically limited to a single-episode analysis in a laboratory setting, and not accessible to all socioeconomic levels.12–18,21 Consequently, there is a critical need to develop an evidence-based screening tool that can be utilized by a diverse group of users, including coaches, instructors, and sports medicine providers to identify youth and adolescent pitchers with at-risk mechanics and strength/flexibility deficits early in their development. Qualitative 2-dimensional (2D) video analysis, in conjunction with observational measurements, has the potential to be a practical, cost-effective clinical assessment.21 The “Assessment of biomechanical Efficiency System” (ACES) is an observational measurement tool that was designed by the authors to evaluate pitching mechanics in young baseball pitchers. The ACES consists of 20 scoring items that are rated by 2D video analysis. Although the ACES is an evidence-based scoring system (Appendix I), its reliability has not been assessed; therefore, the purpose of this study was to evaluate the reliability of the ACES screening tool using 2D video analysis to identify common biomechanical errors in adolescent pitchers. We hypothesized that the ACES tool would demonstrate good intra-rater and inter-rater reliability for identifying biomechanical errors in adolescent pitchers.

METHODS

PARTICIPANTS

Middle school and high school male pitchers with a minimum of two years’ pitching experience were recruited from local high schools and from the study institutions’ sports medicine clinics. Pitchers were males between the ages of 12 and 18 years old. Pitchers with any current injury that affected normal mechanics were excluded. Sidearm or submaine pitchers, defined as pitchers who maintain their pitching arm in a low, approximately horizontal plane (eg, at or below the 9 o’clock position for right-handed pitchers, 3 o’clock position for left-handed pitchers as illustrated in Appendix II), were also excluded from the study.

INSTRUMENTATION/DATA COLLECTION

Testing occurred at two different locations (Rhode Island Hospital and Boston Children’s Hospital.) Following a proper warm-up, all participants performed 10 to 25 fastball pitches using high-speed 2D video analysis. The primary investigator (PKK) reviewed all participants’ videos and selected the one pitch that represented their best effort and fastball mechanics for analysis; kinematic variables were then assessed using 2D motion analysis software (Dartfish Inc.; Alpharetta, GA) with commercially available high-resolution video cameras (GoPro Hero 3, 120 frames per second, San Mateo, CA; Casio Exilim Pro EX-F1, 300 frames per second, Tokyo, Japan) recording from frontal and lateral views. Pitchers threw off an indoor mound (ProMounds; Chatsworth, GA) to a catcher (at Rhode Island Hospital) or to a strike zone target (at Boston Children’s Hospital) at a distance commensurate with their level of play. Visual assessment of the upper extremities, lower extremities, trunk, and pelvis was collected and computed through each phase of the pitching cycle (Figure 1).

Raters used a scoring system (ACES) to assess 20 kinematic variables and observational measurements that were identified by biomechanics researchers to be key features of the pitching cycle15 (Appendices I-III), as well as an overall impression of the thrower’s mechanics. Observational measurements were recorded by each rater for the 20 kinematic variables in a binary fashion (1=error; 0=no error). One point was given for each error in the throwing sequence, with a perfect score being 0 and the worst possible score is 21.

Pitchers’ videos were examined by three raters from different clinical sports medicine specialties (orthopedic surgery resident, physical therapist, and athletic trainer) with varying experience analyzing youth pitching mechanics. All raters participated in a 30-minute training webinar and completed five reviews together prior to study assessments. The ACES tool was used to assess the videos twice, with a washout period of two weeks between rater assessments. The research team intentionally chose raters with

Level of Evidence

3b
Figure 1. Phases of The Overhand Throw


Different career backgrounds because the scoring system was developed for use by a heterogeneous group of evaluators (eg, coaches, instructors, and healthcare providers). This cross-sectional study was approved by the Institutional Review Boards of Rhode Island Hospital and Boston Children’s Hospital.

Statistical Analysis

Data on individual items were summarized as frequencies and percentages across all ratings of pitchers by the three raters. Total scores for each rater were summarized as mean and standard deviation and range. Absolute agreement (%) and Fleiss’ kappa (κ) coefficient were calculated to determine intra- and inter-rater reliability of pitching errors for the individual binary items. Intraclass correlation coefficients (ICC) were calculated to determine intra- and inter-rater agreement on total scores. The ICC values were calculated using two-way random effects modeling (Stata Statistical Software: Release 16; College Station, TX) because the same set of raters scored all the pitchers. Agreement was determined based on established interpretations criteria;22,23 poor agreement (< 0.4), fair to good agreement (0.4 to 0.75), and excellent agreement (> 0.75).

Results

Twenty asymptomatic male pitchers (mean age 15.1 ± 3.1 years old) participated in the study. The ACES total scores ranged from 1 to 15 and were normally distributed with mean scores across raters of 7.5 ± 3.0; 6.7 ± 2.3; and 5.5 ± 2.6, respectively. The ACES total score demonstrated excellent intra-rater reliability within each rater (ICC for rater 1 = 0.99 (95% CI; 0.98, 0.99); ICC for rater 2 = 0.94; 95% CI: 0.84, 0.97); ICC for rater 3 = 0.98 (95% CI: 0.96, 0.99). There was excellent inter-rater reliability across the trials and raters (ICC = 0.91; 95% CI: 0.82, 0.96). For individual items, absolute inter-rater agreement across the three raters ranged from 50% to 100% (Table 1). Intra-rater consistency of individual items was strong, with absolute agreement ranging from 70% to 100%, and kappa values from 0.38 to 1 (Table 1).

Various items were most often recorded as erroneous by the three raters. Specifically, ACES item 10 (Appendix III) which is designated “front side position” in Table 1 and Figure 2, was rated erroneous in 84 of 120 ratings (70%). ACES item 9, stride length, was rated erroneous in 52 of 120 ratings (43.3%). Lead hip position, ACES item 3 during the windup phase, also accounted for many errors (53 in 120 ratings, or 44.2%).

Discussion

The purpose of this study was to determine the reliability of a practical, affordable clinical assessment tool utilizing 2D video analysis for coaches, instructors, and sports medicine providers to screen adolescent pitchers for common biomechanical errors. The ACES scoring tool demonstrated excellent reliability for identifying biomechanical errors in adolescent pitchers when administered by raters of different musculoskeletal disciplines. Regarding each ACES item, there was a diverse range of scores; however, acceptable values were found by weighted kappa analysis overall.

Previous authors have analyzed qualitative kinematic variables during the pitching cycle in adolescent baseball players. Nicholls et al.24 evaluated 20 adolescent baseball pitchers using qualitative 2D and 3D motion analysis to validate kinematic variables from the stride, arm cocking, and arm acceleration/ball release phases. Two raters (an internationally recognized coach and a trained biomechanist) conducted an analysis using a 24-item qualitative analysis protocol of ideal pitching techniques. Intra-rater reliability across two trials was fair to excellent, with all 24 items in the checklist producing kappa between 0.400 and 0.900 (in 22 items, p < 0.05). Inter-rater reliability for the qualitative analysis protocol was fair to good (kappa = 0.468 to 0.694, p < 0.05) on 8/24 (33%) qualitative kinematic variables: four stride phase variables (stride offset, foot angle, shoulder ex-
In an unpublished study (E. Quatromoni, unpublished data, 2015), Quatromoni evaluated 34 adolescent baseball pitchers using high-speed 2D video to assess the intra- and inter-rater reliability of six biomechanical errors [forearm position at stride foot contact (SFC), stride foot position, backward lean at SFC, shoulder position at SFC, trunk to elbow angle at SFC, and contralateral trunk lean at maximal humeral external rotation] of three pitches (trials) analyzed independently by three raters (one former collegiate pitcher and two certified athletic trainers). Regarding intra-rater reliability across the three trials, five of the six biomechanical error items had fair to excellent agreement, producing kappa values between 0.459 and 0.872, \( p < 0.05 \). Only open shoulder position at SFC (specifically trial 2 vs. 3) had poor agreement (kappa = 0.242, \( p > 0.05 \)). Inter-rater reliability across the two trials was fair to excellent, with all 20 items in the checklist producing kappa between 0.47 and 1. Inter-rater reliability for the ACES scoring tool was fair to excellent (kappa = 0.44 to 1) on 10 out of 20 (50%) variables: three windup phase variables (center of gravity, knee height, lead hip), three stride foot contact variables (external rotation at SFC, stride length, and trunk rotation), two acceleration variables (trunk flexion, knee flexion) and two deceleration variables (arm internal rotation, knee extension). Because these 10 variables had acceptable intra- and inter-rater reliability, these 10 items may be considered key components of a scoring system that can be utilized for identifying impaired pitching mechanics.

Davis et al.\textsuperscript{14} evaluated 169 baseball pitchers aged 9 to 18 years using 2D video analysis and 3D motion analysis to determine if correct performance of five biomechanical pitching parameters considered to be key elements in youth

### Table 1. Evaluation of inter- and intra-rater reliability for each item in the ACES scoring tool.

<table>
<thead>
<tr>
<th>ACES Item</th>
<th>Number with condition error among all 120 ratings (%)</th>
<th>Inter-rater reliability (between raters)</th>
<th>Intra-rater reliability (within raters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absolute agreement across raters (Rating 1 / Rating 2)</td>
<td>Fleiss’ kappa*</td>
<td>Absolute agreement within each rater (Rating 1 / Rating 2 / Rating 3)</td>
</tr>
<tr>
<td>Windup</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center of Gravity</td>
<td>37 (30.8%)</td>
<td>78% / 80% / 80%</td>
<td>0.44 / 0.54</td>
</tr>
<tr>
<td>Knee Height</td>
<td>22 (18.3%)</td>
<td>93% / 93% / 78%</td>
<td>0.78 / 0.78</td>
</tr>
<tr>
<td>Lead Hip</td>
<td>23 (19.2%)</td>
<td>77% / 67% / 53%</td>
<td>0.53 / 0.12</td>
</tr>
<tr>
<td>Stroll</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hands Separation/Position</td>
<td>28 (23.3%)</td>
<td>73% / 70% / 70%</td>
<td>0.29 / 0.0</td>
</tr>
<tr>
<td>Hip Rotation</td>
<td>25 (20.8%)</td>
<td>87% / 77% / 70%</td>
<td>0.13 / 0.0</td>
</tr>
<tr>
<td>Hands on Top</td>
<td>24 (20%)</td>
<td>70% / 77% / 77%</td>
<td>0.06 / 0.27</td>
</tr>
<tr>
<td>Time to Lead Foot</td>
<td>8 (6.7%)</td>
<td>67% / 67% / 67%</td>
<td>0.07 / 0.067</td>
</tr>
<tr>
<td>Stride Foot Contact</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External Rotation at SFC</td>
<td>35 (28.1%)</td>
<td>80% / 77% / 77%</td>
<td>0.52 / 0.48</td>
</tr>
<tr>
<td>Stride Length</td>
<td>32 (25.9%)</td>
<td>75% / 75% / 75%</td>
<td>0.46 / 0.46</td>
</tr>
<tr>
<td>Forearm Side Position</td>
<td>34 (27.9%)</td>
<td>73% / 70% / 70%</td>
<td>0.38 / 0.26</td>
</tr>
<tr>
<td>Trunk Rotation</td>
<td>44 (35.7%)</td>
<td>83% / 77% / 70%</td>
<td>0.64 / 0.5</td>
</tr>
<tr>
<td>Arm Cocking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk Flexion</td>
<td>36 (29.8%)</td>
<td>57% / 50% / 50%</td>
<td>0.07 / 0.16</td>
</tr>
<tr>
<td>External Rotation at Max Cocking</td>
<td>7 (5.8%)</td>
<td>90% / 90% / 90%</td>
<td>0.23 / 0.63</td>
</tr>
<tr>
<td>Acceleration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk Flexion</td>
<td>24 (20%)</td>
<td>83% / 83% / 83%</td>
<td>0.38 / 0.08</td>
</tr>
<tr>
<td>Knee Flexion</td>
<td>25 (21.7%)</td>
<td>90% / 90% / 90%</td>
<td>0.71 / 0.71</td>
</tr>
<tr>
<td>Deceleration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm Internal Rotation</td>
<td>0 (0%)</td>
<td>100% / 100% / 100%</td>
<td>1 / 1</td>
</tr>
<tr>
<td>Knee Extension</td>
<td>25 (20.8%)</td>
<td>87% / 87% / 87%</td>
<td>0.63 / 0.55</td>
</tr>
<tr>
<td>Follow Through</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm Across Body</td>
<td>2 (1.7%)</td>
<td>97% / 97% / 97%</td>
<td>-0.01 / -0.01</td>
</tr>
<tr>
<td>Trunk Flexion</td>
<td>25 (20.8%)</td>
<td>70% / 70% / 70%</td>
<td>0.10 / 0.0</td>
</tr>
<tr>
<td>Overall Impairment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td>20 (16.7%)</td>
<td>63% / 67% / 63%</td>
<td>0.18 / 0.31</td>
</tr>
<tr>
<td>Poor</td>
<td>25 (20.8%)</td>
<td>67% / 67% / 67%</td>
<td>0.50 / 0.50</td>
</tr>
</tbody>
</table>

*Fleiss kappa may be an unstable measure and therefore absolute agreement is presented as well.

\(20\) pitchers were each rated twice by three raters, leading to a total of 120 ratings for each ACES item.
pitching (leading with the hips, hand-on-top position, arm in throwing position, closed-shoulder position, and stride foot toward home plate) were associated with decreased joint forces at the shoulder and elbow (humeral internal rotation torque [HIRT] and elbow valgus load [EVL]). Interestingly, pitchers that performed both the hand-on-top and closed-shoulder positions correctly were considered to be more efficient than those pitchers who performed these parameters incorrectly. Several ACES items (items 3, 6, 10) were modeled after the parameters of this study.

Regarding individual ACES items (Figure 2), the authors found that one windup phase variable (leading with the hips) and four stride foot contact phase variables (semi-cocked flexed elbow, abducted and externally rotated shoulder—represented as External Rotation at SFC in Table 1 and Figure 2; stride length; front side position; and trunk rotation) were responsible for 271 out of 548 (49.5%) total errors identified by raters (Table 1). Fifty-three of 120 (44.2%) ratings in the current study identified adolescent pitchers leading with the hips (premature forward momentum). In a descriptive laboratory study, Davis et al. found that 77 of 83 (92.8%) adolescent pitchers demonstrated "leading with the hips" as well. Surprisingly, "leading with the hips" was associated with higher HIRT, higher elbow EVL, and lower pitching efficiency (efficiency defined as normalized HIRT/velocity and normalized EVL/velocity. These ratios indicate the amount of stress the shoulder and elbow are subjected to for a given pitch velocity generated; the higher the value, the lower the efficiency). While increased forces (↑ HIRT, ↑ EVL) cannot be considered causal to increased risk of injury, several authors have suggested that increased HIRT is a contributor to a physiological condition of proximal humeral epiphysiolysis (Little League Shoulder), as well as humeral retroversion, a physiologic adaptation to the proximal humerus that can contribute to increased external rotation and increased velocity. While "leading with the hips" may be necessary for generating ball velocity in youth and adolescent pitchers, it remains unclear whether this parameter should be promoted by pitching coaches since the potential long-term risks (cumulative microtrauma due to increased kinetic forces at the shoulder and elbow) may outweigh transient performance benefits (velocity) in skeletally and physiologically immature pitchers. Consequently, "leading with the hips" was categorized as a biomechanical error rather than a correct parameter in this study.

The culminating event that ends the stride phase (Appendix III), stride foot contact (eg., when the lead foot contacts the ground), has significant biomechanical implications that optimally allow transfer of energy to the distal segments of the kinetic chain. Aberrations in stride length, lead shoulder position (eg, "open" vs. "closed" shoulder position), and stride foot contact position have been associated with increased shoulder and elbow forces as well as decreases in ball velocity, which can result in greater demands on the distal kinetic chain to maintain throwing accuracy and velocity. Stride errors in direction and length can affect trunk rotation velocity and inclination (contralateral trunk tilt) and can lead to the throwing arm lagging behind the scapular plane, which is a known contributor to increased stress on the shoulder and elbow. The results of this study demonstrate that ACES items categorized as stride foot contact variables collectively accounted for the largest percentage of erroneous ratings, perhaps identifying stride foot contact as the most important biomechanical event to objectively assess in adolescent pitchers.
LIMITATIONS

This study had several limitations. While the ACES tool was constructed by those with backgrounds in researching baseball biomechanics, the contribution of each variable to pitching, the kinetic chain, and overall injury risk remains unclear. Additionally, some components of the ACES tool required that several conditions be met to be graded as “correct,” such as item 10 that consisted of three variables for a correct score; this may have increased error in grading the throwing motion.

This small sample of adolescent pitchers likely represented more frequent pitching inefficiencies compared to higher level pitchers; however, adolescents are the largest subset of pitchers in organized baseball, with more than 6 million adolescents participating in organized baseball in the United States. Compared to elite-level pitchers, adolescent pitcher biomechanical studies have been underrepresented in the literature. Single-episode study design and studies using only one pitch for 2D video analysis (including this study) limit the ability to assess for trends, including correction of biomechanical errors and development of mechanical inefficiency with fatigue in pitchers’ biomechanics. Additionally, the ACES tool may not be generalizable to pitchers with different throwing mechanics which are widely regarded as “non-traditional” (ie, side-arm, or submarine pitchers).

As this study was conducted at two clinical research centers, cameras with different speeds (300 and 120 frames per second) were utilized. While not uniform, these frame rates are within the range of commercial equipment available to the consumer, including coaches, parents, and players. Additionally, the use of a catcher or target was not uniform at the two clinical research centers, as one center standardly used a staff member experienced with catching pitchers during 2D video analysis, while the other center utilized a strike zone target. Lastly, non-healthcare providers were not utilized (eg, youth baseball coach) as a rater in this study, limiting the ability to determine the usefulness of the ACES scoring system for a layperson without specialized training in interpretation of adolescent pitching biomechanics.

CONCLUSION

The results of this study indicate that 2D video analysis and an observational screening tool (ACES) to assess pitching kinematics can be used reliably, due to excellent intra- and inter-rater reliability demonstrated by raters of different musculoskeletal disciplines (orthopedic surgeon, physical therapist, certified athletic trainer). Future studies validating 2D video analysis methodology with 3D motion analysis are warranted before the ACES screening tool is disseminated and employed by coaches and instructors of adolescent pitchers.

FINANCIAL DISCLOSURE

The authors have no applicable financial disclosures.

CONFLICTS OF INTEREST

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

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REFERENCES


SUPPLEMENTARY MATERIALS

Appendix 1

Appendix 2

Appendix 3
Original Research

The Intra- and Inter-rater Reliability of an Arm Care Screening Tool in High School Baseball Coaches

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1 University of Kentucky; University of Evansville, 2 University of Kentucky, 3 Saint Louis Cardinals Baseball Organization

Keywords: screening, reliability, movement system, baseball

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Background
Preseason movement screening can identify modifiable risk factors, deterioration of function, and potential for injury in baseball players. Limited resources and time intensive testing procedures prevent high school coaches from accurately performing frequent movement screens on their players.

Purpose
To establish the intra-rater and inter-rater reliability of a novel arm care screening tool based on the concepts of the Functional Movement Screen (FMS™) and Selective Functional Movement Assessment (SFMA™) in high school coaches.

Study Design
Methodological intra- and inter-rater reliability study

Methods
Thirty-one male high school baseball players (15.9 years ± 1.06) were independently scored on the Arm Care Screen (ACS) by three examiners (two coaches, one physical therapist) in real-time and again seven days later by reviewing video recordings of each players' initial screening performance. Results from each examiner were compared within and between raters using Cohen's kappa and percent absolute agreement.

Results
Substantial to excellent intra-rater and inter-rater reliability were established among all raters for each component of the ACS. The mean Cohen’s kappa coefficient for intra-rater reliability was 0.76 (95% confidence interval, 0.54-0.95) and percent absolute agreement ranged from 0.82-0.94 among all raters. Inter-rater reliability demonstrated a mean Cohen's kappa value of 0.89 (95% confidence interval, 0.77-0.99) while percent absolute agreement between raters ranged from 0.81-1.00. Intra- and inter-rater reliability did not differ between raters with various movement screening experience (p>0.05).

Conclusions
High school baseball coaches with limited experience screening movement can reliably score all three components of the ACS in less than three minutes with minimal training.

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Level of Evidence

Level 3, Reliability study

INTRODUCTION

Baseball players are susceptible to shoulder and elbow injuries which can result in missed time from sport. Micro-trauma from repetitive physical misuse of the kinetic chain is a common avenue for development of injury. Overhead throwing motion, common in baseball, requires contribution of the entire body, specifically the hips, torso, and shoulder girdle. Limitations in any of these body regions can result in large amounts of mechanical stress placed on the upper extremity. Despite well-established pitching volume guidelines, injury rates in high school baseball players have continued to increase. Over the past two decades, elbow injuries, specifically ulnar collateral ligament reconstruction, have become more frequent in adolescents and are expected to continue to rise. As a result, greater attention to identification and management of intrinsic modifiable risk factors such as strength, flexibility, and neuromuscular control is warranted for more comprehensive injury management.

Preseason examinations have identified modifiable risk factors associated with increased injury rates during the season. Movement screening can provide useful information specific to deterioration of function and potential for injury. Two movement examination tools that exist are the Functional Movement Screen (FMS) and the Selective Functional Movement Assessment (SFMA) which are designed to identify major limitations and/or asymmetries which could contribute to musculoskeletal pain or movement deficits. In high school baseball players, Lee et al. reported that FMS composite scores and individual test performance declined over the course of the season. Most studies have focused on singular risk factors in common body regions while overlooking the presence of additional impairments throughout the kinetic chain. In collegiate baseball players, Busch et al. reported that poor FMS and SFMA shoulder mobility patterns were associated with five and six-fold increased odds of having an overuse injury during preseason training, respectively. However, Busch et al. limited screening to only upper quarter tests and failed to include additional lower quarter movement patterns which would be more representative of the entire kinetic chain.

Physical limitations throughout the kinetic chain can contribute to upper extremity overuse injury in baseball players. The functional relationship between the upper extremities, spine, and hips required for kinetic linkage in rotational athletes warrants a more comprehensive screen of the entire body. Although the shoulder and elbow are common areas for symptom development, increased physiological stress on these joints can be produced by other remote regions in the body. Risk factors such as glenohumeral internal rotation deficit (GIRD), limited hip internal rotation ROM, limited hip external rotation, thoracic spine mobility, total shoulder ROM, and dynamic single leg balance have been identified during comprehensive pre-season examinations and can result in time loss from sport.

In most circumstances, high school coaches have limited resources needed to perform frequent movement screenings on their players. External factors such as funding for training, time constraints, and insufficient staffing limit implementation of injury screening. Specifically, the FMS requires testing equipment, multiple hours of training for certification, and takes approximately 10-15 minutes to perform on each player. The SFMA is a clinical assessment designed for practitioners with a license to diagnose and treat pain and therefore is out of the scope of practice for the coach. Thus, there is a need for a field expedient screening tool which can measure physical function throughout the kinetic chain that can quickly be administered by coaches. Frequent screening throughout the season could identify impairments and inform arm care training programs to improve strength and flexibility.

To date there are no studies which have explored a field expedient screening tool that can be quickly performed by high school baseball coaches. The primary purpose of this study was to establish the intra-rater and inter-rater reliability of a novel arm care screening tool based on the concepts of the FMS and SFMA in high school coaches. It was hypothesized that the Arm Care Screen (ACS) will demonstrate moderate intra-rater and inter-rater reliability with a Cohen’s kappa value >0.40 when administered by high school baseball coaches.

MATERIALS AND METHODS

STUDY DESIGN

A prospective methodological cohort design was used to establish the intra-rater and inter-rater reliability of the ACS among high school baseball coaches. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement was used for quality reporting. Approval was granted from the institutional review board at the University of Kentucky and informed consent and assent forms were obtained prior to data collection.

PARTICIPANTS

A minimum sample size of 24 players was needed to achieve a Cohen’s kappa value of 0.40 with an alpha of 0.05 and 80% power for a two-tailed test. Anticipating 10% of the participants would have missing or incomplete data the planned target sample size was 27 participants. A convenience sample of 31 male high school baseball players from a single local team volunteered to participate in this study. The head coach allowed the researchers to attend team workouts to recruit and test the players. Inclusion criteria required the participant to be a current and active member of a men’s varsity, junior varsity, or freshman high school baseball team. Exclusion criteria included the inability to participate in sport due to current injury, recent surgery (within three months), physician restriction, recent concussion (within one month) or vestibular issue. Players who were under the
age of 14 or older than 18 were excluded (Figure 1).

PROCEDURES

Data collection occurred over a four-week period in the fall offseason during team workouts. Physical testing occurred during a single session at the participants’ local high school baseball field. Participants completed a demographic questionnaire which included information about their age, height, weight, playing position, baseball experience, and current injury status. All participants were scored once on ACS performance in real-time while being videotaped for later assessment of intra-rater reliability.

The ACS is a modified movement-based screening tool which utilizes components of the FMS™, SFMA, and Y-Balance Test-Lower Quarter developed to improve field expediency and reduce scoring complexity. The ACS consists of three tests including, 1) reciprocal shoulder mobility, 2) 90/90 total body rotation, and 3) lower body (LB) diagonal reach (Figure 2). Each component of the ACS was scored as pass or fail per the criteria below on both the right and left sides. Pain with testing was recorded but did not factor into the scoring criteria.

Reciprocal Shoulder Mobility: The participant began in standing with feet together and both hands open. The participant simultaneously reached one hand behind their head and other hand behind and up their back, similar to an Apley’s Scratch test position, assuming an extended and internally rotated position with one shoulder and a flexed and externally rotated position with the other. The arms must move in one smooth motion and tall posture must be maintained while the participant attempts to touch the fingertips of both hands together. Inability to touch right and left fingertips together on both reach directions was considered a failure in the test.

90/90 Total Body Rotation: The participant assumes a standing position with feet together, toes pointing forward and arms in the 90/90 position (90° shoulder abduction and 90° elbow flexion). The participant rotates their entire body including the hips, shoulders, and head as far as possible to the right while the foot position remained unchanged. Inability to see the back shoulder when viewing the participant from behind on both sides was considered failure on the test.

Lower Body Diagonal Reach: The participant stood two shoe lengths away from a wall and while maintaining single leg balance on one foot the participant reaches with the opposite foot behind and across their body to try to touch the point on the wall just above the ground five consecutive times without the foot touching down or losing balance. Inability to touch the wall five consecutive times or loss of balance on either side was considered failure on the test.

INTRA-RATER AND INTER-RATER RELIABILITY

Two high school baseball coaches were recruited to each score the ACS at two different time points. Prior to data collection, both coaches signed the informed consent and underwent a one-hour electronic ACS training session performed by the lead author (KAM). Following the training session, both coaches were required to pass an online ACS competency examination with a score of ≥80% prior to data collection. Additional online training and a retake exam would be provided for coaches scoring <80% on the exam. Remediation was not required in this study since both coaches passed their exam on the first attempt.

The participants were given the ACS instructions by one rater (KAM) while the testing was observed by two other raters simultaneously in real-time. All raters were blinded to each other’s scoring. The PT rater (KAM) was a physical therapist with 10 years of experience working with baseball players and coach rater 1 (C1) (JB) and coach rater 2 (C2) (TO) were assistant high school baseball coaches with greater than five years of coaching experience. All participants were video recorded performing the ACS testing procedures during the live testing using an iPhone 10X cell phone placed approximately 15 feet directly posterior to the participant. Following a seven-day washout period, the same three raters rescored the ACS performance using the
Table 1. Descriptive Characteristics of High School Baseball Players

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>15.9 ± 1.06</td>
</tr>
<tr>
<td>Height, cm</td>
<td>178.9 ± 6.6</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>72.2 ± 10.3</td>
</tr>
<tr>
<td>Dominant limb, n (%)</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>27 (87.1)</td>
</tr>
<tr>
<td>Left</td>
<td>4 (12.9)</td>
</tr>
<tr>
<td>Years of Baseball Experience</td>
<td>10.2 ± 2.65</td>
</tr>
<tr>
<td>Year in School, n (%)</td>
<td>14 (45.2)</td>
</tr>
<tr>
<td>Freshman</td>
<td>5 (16.1)</td>
</tr>
<tr>
<td>Sophomore</td>
<td>14 (45.2)</td>
</tr>
<tr>
<td>Junior</td>
<td>7 (22.6)</td>
</tr>
<tr>
<td>Senior</td>
<td>5 (16.1)</td>
</tr>
<tr>
<td>Primary Position, n (%)</td>
<td></td>
</tr>
<tr>
<td>Pitcher</td>
<td>8 (25.8)</td>
</tr>
<tr>
<td>Catcher</td>
<td>1 (3.2)</td>
</tr>
<tr>
<td>Infield Player</td>
<td>12 (38.7)</td>
</tr>
<tr>
<td>Outfield Player</td>
<td>10 (32.3)</td>
</tr>
</tbody>
</table>

*SD=standard deviation, y=year

video recordings taken during the live testing and were blinded to each other’s results. To minimize recall bias, the order of the videos was randomized to differ from the original live testing order.

STATISTICAL METHODS

Descriptive statistics including means and standard deviations (SD) or frequency counts were calculated as appropriate. Intra-rater and inter-rater reliability for the categorical scores of each component of the ACS were compared within and between (PT-C1, PT-C2, and C1-C2 each rater using Cohen’s kappa coefficient with 95% confidence intervals (CI95%) and percent absolute agreement. The Cohen’s kappa coefficient quantifies the strength of agreement and was interpreted as: ≤0.40 = poor to slight, 0.41-0.60 = moderate, 0.61-0.80 = substantial, ≥0.80 = excellent. All data analyses were performed with SPSS statistical software (IBM SPSS Statistics for Mac, Version 27.0). An alpha level of \( p < 0.05 \) was considered statistically significant for all tests.

RESULTS

Demographic characteristics of all participants are provided in Table 1. The mean age ± SD of the participants in this sample was 15.9 ± 1.06, 45.2% (n=14/31) were high school sophomores, and 25.8% (n=8/31) were primarily pitchers. A total of 29% (n=9/31) of participants reported pain, which was defined as discomfort beyond just a stretch or soreness, with at least one component of the ACS, however, pain was not part of the passing criteria for the tests and did not affect the scoring. All 31 participants completed the testing procedures, and the results were used for data analysis.

INTRA-RATER AND INTER-RATER RELIABILITY

Results of intra-rater reliability scores after a seven-day washout period within all three raters are presented in Table 2 including corresponding Cohen’s kappa values with 95% confidence intervals and percent agreement. Cohen’s kappa values for the three component tests of the ACS (scored pass or fail) demonstrated moderate to excellent intra-rater agreement. The mean intra-rater reliability for all raters was substantial with a Cohen’s kappa value of 0.76 (95% CI, 0.54-0.95) and a mean absolute agreement was 89%. The PT rater demonstrated higher intra-rater reliability compared to C1 and C2, but these differences were not statistically significant (\( p > 0.05 \)).

The results for ACS same day inter-rater reliability with Cohen’s kappa values, 95% confidence intervals, and percent absolute agreement are presented in Table 3. Cohen kappa values ranged from moderate to excellent agreement between all three raters depending on the specific movement component of the ACS. The mean inter-rater reliability for all raters was excellent with a Cohen’s kappa value of 0.89 (95% CI, 0.77-0.99) and a mean absolute agreement was 95%. The overall mean kappa agreement when comparing each raters’ performance on all ACS components demonstrated near perfect agreement and did not differ significantly between raters (\( p > 0.05 \)).

DISCUSSION

The purpose of this study was to establish the intra- and inter-rater reliability of a field expedient arm care screening tool in a sample of high school baseball players. The findings from this study supports the primary hypothesis that...
The Intra- and Inter-rater Reliability of an Arm Care Screening Tool in High School Baseball Coaches

Table 2. Intra-rater Reliability of ACS Components (n=31)

<table>
<thead>
<tr>
<th></th>
<th>PT Rater</th>
<th>C1 Rater</th>
<th>C2 Rater</th>
<th>All Raters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kappa (CI95%)</td>
<td>% Agree</td>
<td>Kappa (CI95%)</td>
<td>% Agree</td>
</tr>
<tr>
<td>NonDom Shoulder Mobility</td>
<td>0.81 (0.60-1.0)</td>
<td>0.90</td>
<td>0.62 (0.36-0.87)</td>
<td>0.81</td>
</tr>
<tr>
<td>Dom Shoulder Mobility</td>
<td>1.0 (1.0-1.0)</td>
<td>1.00</td>
<td>0.78 (0.56-1.0)</td>
<td>0.90</td>
</tr>
<tr>
<td>NonDom Total Body Rotation</td>
<td>0.80 (0.59-1.0)</td>
<td>0.90</td>
<td>0.74 (0.49-0.98)</td>
<td>0.87</td>
</tr>
<tr>
<td>Dom Total Body Rotation</td>
<td>0.83 (0.61-1.0)</td>
<td>0.94</td>
<td>0.74 (0.46-1.0)</td>
<td>0.90</td>
</tr>
<tr>
<td>Stride LB Diagonal Reach</td>
<td>0.60 (0.32-0.87)</td>
<td>0.81</td>
<td>0.87 (0.70-0.78)</td>
<td>0.94</td>
</tr>
<tr>
<td>Stance LB Diagonal Reach</td>
<td>0.68 (0.43-0.93)</td>
<td>0.84</td>
<td>0.50 (0.22-0.83)</td>
<td>0.74</td>
</tr>
<tr>
<td>Mean</td>
<td>0.79 (0.59-0.97)</td>
<td>0.90</td>
<td>0.71 (0.47-0.91)</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Nondom=nondominant arm, Dom=dominant arm, LB=lower body, CI95%=95% confidence interval

Table 3. Inter-rater Reliability of ACS Components (n=31)

<table>
<thead>
<tr>
<th></th>
<th>PT Rater vs. C1</th>
<th>PT Rater vs. C2</th>
<th>C1 Rater vs. C2</th>
<th>All Raters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kappa (CI95%)</td>
<td>% Agree</td>
<td>Kappa (CI95%)</td>
<td>% Agree</td>
</tr>
<tr>
<td>NonDom Shoulder Mobility</td>
<td>1.0 (1.0-1.0)</td>
<td>1.00</td>
<td>1.0 (1.0-1.0)</td>
<td>1.00</td>
</tr>
<tr>
<td>Dom Shoulder Mobility</td>
<td>0.92 (0.76-1.0)</td>
<td>0.97</td>
<td>0.92 (0.76-1.0)</td>
<td>0.97</td>
</tr>
<tr>
<td>NonDom Total Body Rotation</td>
<td>0.73 (0.48-0.97)</td>
<td>0.87</td>
<td>0.86 (0.67-1.0)</td>
<td>0.93</td>
</tr>
<tr>
<td>Dom Total Body Rotation</td>
<td>0.91 (0.74-1.0)</td>
<td>0.97</td>
<td>0.91 (0.75-1.0)</td>
<td>0.97</td>
</tr>
<tr>
<td>Stride LB Diagonal Reach</td>
<td>0.81 (0.60-1.0)</td>
<td>0.93</td>
<td>0.67 (0.41-0.93)</td>
<td>0.84</td>
</tr>
<tr>
<td>Stance LB Diagonal Reach</td>
<td>0.94 (0.81-1.0)</td>
<td>0.97</td>
<td>0.87 (0.70-1.0)</td>
<td>0.94</td>
</tr>
<tr>
<td>Mean</td>
<td>0.88 (0.73-0.99)</td>
<td>0.95</td>
<td>0.87 (0.72-0.99)</td>
<td>0.94</td>
</tr>
</tbody>
</table>

* Nondom=nondominant arm, Dom=dominant arm, LB=lower body, CI95%=95% confidence interval

baseball coaches can reliably administer the ACS to screen high school players for physical limitations which may contribute to time loss from sport and determine need for further evaluation by a healthcare professional. All three subcomponents of the ACS, scored as pass or fail, exhibited substantial to excellent intra- and inter-rater reliability among all three raters regardless of their coaching or movement screening experience. The reliability of movement-based screening tools has been evaluated in multiple populations among raters of differing professional backgrounds such as physical therapists, certified athletic trainers (ATC), and strength and conditioning specialists.41–43 The results of the current study are similar to previous literature investigating rater agree-
ment of the FMS™ and SFMA. Mininck et al.44 reported substantial to excellent interrater reliability (κr = 0.74-1.0) among expert FMS raters and novice raters while scoring FMS™ performance from video recordings. Likewise, Teyhen et al.41 reported moderate to excellent interrater and test-retest agreement in physical therapy students on the component tests of the FMS when scored in real time. Moderate intra-rater (ICC = 0.75; 95% CI, 0.53-0.87) reliability has been observed among ATCs and athletic training students when evaluating the composite score of the FMS™ in real time.42 Conversely, Shultz et al.45 which included strength and conditioning coaches, showed fair to poor inter-rater reliability (K = 0.38; 95% CI, 0.35-0.41) of FMSTM subsets.

The SFMA categorical scoring criteria have demonstrated slight to substantial intra-rater (κ=0.48-0.83) and inter-rater (κ=0.20-0.76) reliability in healthy adults.37,45 However, reliability limitations are limited to only physical therapists and ATCs to date. This is the first study to specifically examine the ability of high school baseball coaches to screen movement patterns accurately and consistently. Previously, three studies exploring the reliability of the SFMA used video analysis to aid with rater scoring.37,45,46 The methodology of the current study included both real-time scoring and video analysis to establish reliability of the ACS. Although video analysis was consistent with previous SFMA reliability studies, the utility of the ACS is more applicable to coaches in scoring players in real-time during practice which warranted exploration of live screening accuracy.

Previous authors have reported that raters with more movement testing experience have better intra-rater and interrater reliability compared to less experienced raters.37,42,45 In the current study, there was no reliability differences between raters even though the PT rater had 10 years of experience screening movement while C1 and C2 only had a one-hour educational session prior to data collection. It is likely that the reduced number of categorical scoring options compared to other movement screens minimized errors among the raters. By dichotomizing each subtest of the ACS as pass or fail scoring complexity is reduced and the raters are better able to agree on the testing results regardless of their experience.

Resources, experience, and staffing limitations prevent high school coaches from performing comprehensive musculoskeletal assessments and testing on their players multiple times during the season. The ACS provides coaches with a tool to track changes in physical function throughout the season so that exercise intervention and/or further evaluation can be recommended prior to the onset of injury. High school coaches can perform the ACS is less than three minutes which is more time efficient and feasible compared to the 10-15 minutes needed to administer the FMS. Furthermore, minimal training (~one hour) is required to be proficient in scoring the ACS with no additional costs or certification required to implement. While the ACS has shown to be reliable, validation of the screening tool is warranted prior to mainstream use in high school athletics. Future research should investigate the discriminability of the ACS to detect physical impairments and risk factors in baseball players.

LIMITATIONS

The authors acknowledge that this study is not without limitations. First, external validity of the intra-rater reliability may have been affected by performing live screens initially but rescreening seven days after from a video recording. During live screening the raters where able to view the participants movement from multiple different angles as opposed to only a singular posterior view on the video recording. Despite the different scoring approaches, Cohen's kappa values were not drastically affected as intra-rater reliability was excellent among all raters. Secondly, the current study focused specifically on high school baseball players who played a variety of positions. The results of this study may not be generalizable to baseball players at the professional and collegiate level. Only high school players were included to maximize homogeneity of the sample, however, both position players and pitchers were also included. Musculoskeletal function differs between pitchers and position players and likely resulted in increased heterogeneity among the participants.

CONCLUSION

High school baseball coaches with limited experience screening movement can reliably score all three components of the ACS in less than three minutes with minimal training. All raters demonstrated substantial to excellent intra- and inter-rater reliability which did not differ based on screening experience. Therefore, the ACS is a highly feasible movement screening option for implementation in the high school baseball environment. Future research should focus on exploring the discriminant validity of the ACS at identifying physical impairments and injury risk factors.

ACKNOWLEDGEMENTS

The authors would like to thank Evansville North High School and head baseball coach Jeremy Jones for access to the players and assistant coaches Tyler Owen and Jordan Bedwell for assistance with data collection. None of the authors of this article have any conflicts of interest or financial conflicts to report.

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REFERENCES


Original Research

Ultrasonographic Validation for Needle Placement in the Tibialis Posterior Muscle

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¹ Physical Therapy, Regis University, ² Physical Therapy, Baylor University

Keywords: ultrasound imaging, posterior tibialis tendon dysfunction, dry needling

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Background

The tibialis posterior (TP) muscle plays an important role in normal foot function. Safe, efficacious therapeutic approaches addressing this muscle are necessary; however, the location of the muscle in the deep posterior compartment can create challenges.

Purpose

The purpose of this study was to assess the accuracy of needle placement in the TP muscle and determine the needle placement in relation to the neurovascular structures located within the deep compartment.

Design

Cross Sectional Study.

Methods

Needle placement and ultrasound imaging were performed on 20 healthy individuals. A 50 mm or 60 mm needle was inserted between 30 - 50% of the tibial length measured from the medial tibiofemoral joint. The needle was inserted in a medial to lateral direction into the right extremity with the patient in right side lying. Placement of the needle into the TP muscle was verified with ultrasound imaging, and the shortest distance from the needle to the posterior tibial artery and tibial nerve was measured. The depth from the skin to the superficial border of the TP muscle was also measured.

Results

Ultrasonography confirmed the needle filament was inserted into the TP muscle in all 20 individuals and did not penetrate the neurovascular bundle in any individual. The mean distance from the needle to the tibial nerve and posterior tibial artery was 10.0 + 4.7 mm and 10.2 + 4.7 mm respectively. The superficial border of the TP muscle from the skin was at a mean depth of 25.8 + 4.9 mm.

Conclusion

This ultrasound imaging needle placement study supports placement of a solid filament needle into the TP muscle with avoidance of the neurovascular structures of the deep posterior compartment when placed from a medial to lateral direction at 30-50% of the tibial length.

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Fax: 303-964-5474
E-mail: albin149@regis.edu
INTRODUCTION

The tibialis posterior (TP) muscle is the main dynamic stabilizer of the medial longitudinal arch and is critical to normal foot function during gait. It is located in the deep posterior compartment of the lower limb along with the posterior tibial artery and vein and the tibial nerve. The muscle becomes a tendon in the distal third of the leg. The tendon passes posterior to the medial malleolus where it is held in place by the flexor retinaculum. By virtue of its position posterior to the axis of the talocrural joint and medial to the subtalar joint, the tibialis posterior muscle is responsible for plantarflexion and inversion and helps to create a rigid lever by locking the hindfoot for efficient push-off at terminal stance.

Several factors can lead to overuse and degeneration of the tendon. The TP is constantly resisting arch flattening effects of the triceps surae. Shortening of the triceps surae can lead to excessive eversion during stance phases of gait. When the hindfoot is in an everted position in the late stance phase of gait, the midfoot complex is unlocked. This position can place excessive forces through stretching of the static structures that support the medial longitudinal arch such as the plantar ligaments. As these static structures begin to lose integrity, the load on the posterior tibialis muscle increases to compensate for the soft tissue laxity. Over time, decreased support from the posterior tibialis muscle can result in flat foot deformity. Therefore, the TP is an important muscle to consider clinically when creating a therapy management plan for individuals with foot and ankle pathology.

Dry needling is an invasive procedure in which a solid filament needle is inserted into muscles in an attempt to reduce pain and normalize muscle function. Dry needling has been shown to be a valuable clinical adjunct to the management of individuals with a variety of lower extremity conditions. Although dry needling may be effective for individuals with lower extremity injuries, it is important to recognize that, although rare, significant complications may result from needling intervention. In the largest study to date documenting adverse events after dry needling, Brady et al. reported that approximately 8% of patients exhibited bleeding, 5% exhibited bruising, and 0.01% reported lasting numbness after dry needling. A recent case study specifically described a radial nerve injury resulting in wrist drop following a dry needling session to the lateral aspect of the upper arm around the distal third of the humerus, which had yet to resolve. Although vascular injuries appear to be fairly common after dry needling, no serious adverse consequences have been reported. Nerve injuries after dry needling appear to be rare, but may cause lasting effects and create substantial disability.

Due to the location in the deep posterior compartment, determining accurate placement of a needle into the TP muscle is difficult to confirm. In addition, reliably avoiding the posterior tibial artery and vein and the tibial nerve may be challenging due to their proximity to the TP muscle. Diagnostic ultrasound imaging has been shown to reliably measure the thickness of tibialis posterior muscle and identify muscle contraction. Ultrasound has been utilized in previous studies to confirm needle placement, but not of the TP muscle. Therefore, given the clinical relevance of the TP muscle for normal foot and ankle function, the purpose of this study was to assess the accuracy of needle placement in the TP muscle and determine the needle placement in relation to the neurovascular structures located within the deep compartment.

METHODS

This study was approved by the Human Research Ethics Committee of Regis University and was performed in accordance with the Declaration of Helsinki. Twenty healthy participants signed an informed consent prior to their inclusion in the study. Participants were excluded if they had operative treatment of their lower extremity within the past 3 months, had received dry needling within the past 30 days, were pregnant, had a history of systemic disorders in which dry needling would be contraindicated (bleeding disorders or current anticoagulant medication use), or were immunocompromised. This population was a sample of convenience and participants were recruited by word of mouth. Individuals’ height and weight were documented.

DRY NEEDLING PROCEDURE

Dry needling was performed in routine clinical fashion without ultrasound guidance. Filament placement was initially estimated consistent to clinical practice, and then the distance from the medial joint line was measured and recorded. Sterile stainless-steel needles with a plastic cylindrical guide, 50mm or 60 mm in length and .50 mm caliber were used. The length of needle selected for the procedure was based on the size of the individual’s leg. A “clean technique” was utilized which included hand washing, sterile latex-free gloves, and cleaning the skin with alcohol prior to needle insertion. The participant was positioned in a right side-lying position for the procedure, and the right posterior tibialis was needled in all individuals. The tibia was measured from the medial joint line to the tip of the medial malleolus and the needle placement occurred between approximately 50-50% of the tibial length measured from the medial joint line. This is consistent with previous research assessing reliability of ultrasound imaging of the tibialis posterior muscle. In addition, this range was selected to target more of the muscle belly of the tibialis posterior given the muscle transitions to tendon more distally in the deep posterior compartment. Due to the location of the TP muscle within the deep posterior compartment and the inability to directly palpate the muscle, the needle approach and insertion was based on anatomical aspects. The neurovascular bundle lies posteriorly within the deep posterior compartment and therefore, the needle was inserted parallel to the border of the tibia from a medial to lateral direc-
tion avoiding a posterior angulation (Figure 1).

ULTRASOUND IMAGING

After the filament was placed, a Sonimage ultrasound unit with a 4-15 MHz linear transducer (Konica Minolta, Wayne, NJ) was utilized to verify anatomic placement. Sterile ultrasound gel was used on all individuals. All ultrasound imaging was conducted by a physical therapist with 10 years of experience in musculoskeletal ultrasound imaging. The physical therapist performing the ultrasound imaging had been mentored in the use of diagnostic ultrasound by experienced practitioners and had done training provided by the manufacturer as well as continuing education courses. Images were performed in short axis of the posterior tibialis muscle (Figure 2). All superficial musculature was identified in addition to the neurovascular bundle (Figure 3). The simple needle visualization (SNV) setting of 6 was used and the needle contrast was set at medium. The depth and time-gain-compensation were adjusted as needed to enhance clarity of the image. Once the needle was in place, the transducer was moved and positioned until the needle was displayed on its longitudinal axis. The needle was left in place throughout the procedure and light pistoning was used to confirm the needle imaging. Screen capture via frozen image was utilized, and the shortest distance from the needle to tibial nerve was measured. The screen was unfrozen, and the Power Doppler mode was turned on to identify the posterior tibial artery. Again, the screen was frozen and the shortest distance from the needle to the posterior tibial artery was measured (Figure 4). The needle was then removed from the participant, and the depth from the skin to the most superficial border of the TP muscle where the needle had been inserted was measured (Figure 5).

DATA ANALYSES

Data analyses were performed using SPSS Version 27.0 statistical package (IBM Corporation, Armonk, NY). Baseline characteristics were summarized. Averages and standard deviations of the distance from the needle to the posterior tibial artery and tibial nerve were calculated. Previous studies utilizing ultrasound imaging to validate needle placement have included a sample size of 10-20 individuals; therefore, this study included a sample size of 20 individuals.21,22

RESULTS

Needling and ultrasound imaging of the posterior tibialis muscle was conducted on 20 healthy individuals (8 male and 12 female) between November 2020 and February 2021. See Table 1 for baseline characteristics. A 50 mm filament was used in 8 (40%) of the individuals and a 60 mm filament for the remaining 12 (60%) of individuals, and the size of needle selected for the procedure was based on the size of the individual’s leg. The average needle placement was 41.1% ± 4.7 % the length of the tibia as measured from the medial joint line. No individuals in this study incurred any serious adverse events. Three individuals (15%) experienced a minor adverse event consisting of minimal bleeding that ceased in less than a minute of the needle being withdrawn. Ultrasound imaging confirmed that the needle was in the tibialis posterior muscle in all 20 individuals. The needle was not inserted into the neurovascular bundle in any individual. See Table 2 for results. The superficial border of the tibialis posterior muscle from the skin was at a mean depth of 25.8 ± 4.9 mm.

DISCUSSION

The importance of the tibialis posterior muscle in normal foot function cannot be understated. Therefore, identifying interventions that promote the health of this structure is imperative. Research has demonstrated that dry needling can help increase blood flow, improve muscle activation, and affect muscle stiffness.24–26 Therefore, needling of the tibialis posterior may be prudent within overall patient management. The results of this current ultrasound study demonstrate that the tibialis posterior muscle can be con-
Table 1. Participant Demographics.

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD*</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>45.3 ± 12.2</td>
<td>20.8 to 60.4</td>
</tr>
<tr>
<td>Number of male/female participants</td>
<td>8/12</td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.5 ± 3.4</td>
<td>17.3 to 30.0</td>
</tr>
<tr>
<td>Tibial length (cm)</td>
<td>38.8 ± 2.8</td>
<td>34.0 to 46.0</td>
</tr>
</tbody>
</table>

BMI, body mass index, cm, centimeters
*Mean and SD reported unless otherwise noted.

Table 2. Results for Needle Placement and Distance from Neurovascular Bundle.

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD*</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average needle placement along the length of tibia (%)</td>
<td>41.1 ± 4.7</td>
<td>30 to 50</td>
</tr>
<tr>
<td>Distance from needle to tibial nerve (mm)</td>
<td>10.0 ± 4.7</td>
<td>3.5 to 17.9</td>
</tr>
<tr>
<td>Distance from needle to posterior tibial artery (mm)</td>
<td>10.2 ± 4.7</td>
<td>2.1 to 18.8</td>
</tr>
</tbody>
</table>

mm, millimeters

Consistently needled, noting no individuals in this study incurred any serious adverse events. The needle was not inserted in the neurovascular structures in any individuals.

Due to the deep anatomical nature of the tibialis posterior muscle, it cannot be directly palpated. Therefore, dry needling may be an important therapeutic tool for individuals with posterior tibial dysfunction. However, it is important to note that in some individuals, the needle was 2.1 mm away from the posterior tibial artery and 3.5 mm away from the tibial nerve. In this study, the needle was inserted in close proximity to the tibia in a medial to lateral direction running parallel to the posterior border of the tibia. It may be important for clinicians to keep in mind that if the needle is angled more posterior instead of running parallel to the posterior border of the tibia, it is likely to be in closer proximity to the neurovascular structures. The mean depth of the superficial border of the TP muscles was 25.8 ± 4.9 mm. Previous research has demonstrated that the largest bulk of the TP muscle belly is located between 30% and 50% of the length of the tibia as measured from the medial joint line. The cross-sectional area of the TP muscle at this location is approximately 3.5 to 4.0 cm². This is important for clinicians to consider when determining appropriate needle length for needling the TP muscle, and in this study supports the selection of 50-60mm filament/needle length allowing for 1-2 cm filament length outside of the body at full insertion.

While this study preliminarily validates that clinicians can safely place a solid filament needle into the TP muscle, potential limitations should be recognized. One limitation of this study is that all needling was performed by one experienced clinician with greater than six years of experience in dry needling, and therefore, it is not known if the accuracy of this needling approach can be extrapolated to less experienced clinicians. As this study did not assess the effectiveness of dry needling of the TP in individuals with dysfunction, future randomized controlled trials in patients with potential TP dysfunction should be performed and include dry needling as currently described. Lastly, it is important to keep in mind that variations in anatomy exist which could impact the risk of the needling procedure in a larger sample of individuals. The point where the popliteal artery bifurcates into the posterior and anterior tibial arteries is fairly regular. The split takes place proximally and deep to the origin of the soleus. If there is a variation in the posterior tibial artery, it is typically a variation of the fibular artery as the fibular artery usually branches off of the posterior tibial artery distal to the formation of the posterior tibial artery.27

Figure 3. Ultrasound image of the neurovascular bundle in the deep posterior compartment.
CONCLUSIONS

Preliminary data from this ultrasound imaging study indicate that placement of a solid filament needle into the TP muscle with avoidance of the neurovascular structures of the deep posterior compartment is promising; however, further validation studies are needed.

FINANCIAL DISCLOSURE

We affirm that we have no financial affiliation or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript, except as cited in the manuscript.

STATEMENT OF INSTITUTIONAL REVIEW BOARD

This study was approved by Regis University's Institutional Review Board.

Submitted: March 23, 2021 CST, Accepted: September 19, 2021 CST

Figure 4. Ultrasound image illustrating the distance from the needle to the posterior tibial artery.

Figure 5. Ultrasound image illustrating the distance from skin to the most superficial border of the tibialis posterior muscle.

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REFERENCES


Original Research

Perceived Management of Acute Sports Injuries and Medical Conditions by Athletic Trainers and Physical Therapists

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Keywords: sports physical therapy, residency, event coverage, decision-making, athletic training, acute injuries

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Background

While Athletic Trainers' (ATs) education emphasizes sport event coverage, Physical Therapists' (PTs) education may prepare them for event coverage responsibilities. The objectives of this study were to compare the perceived preparedness and decision-making related to acute injury/medical condition management among ATs and PTs and evaluate the relationship between perceived preparedness and decision-making.

Hypothesis

ATs would report greater perceived preparedness and appropriate decision-making related to acute injury/medical conditions compared to PTs.

Study Design

Cross-sectional, Online survey

Methods

An electronic survey was disseminated to licensed ATs (n=2,790) and PTs (n=10,207). Survey questions focused on perceived preparedness for management of acute injuries/medical conditions. Respondents also completed questions that assessed clinical decision-making related to acute injury case scenarios. Kruskal-Wallis H-Tests and Spearman’s Rho Correlations were used for the analysis. Significance was set to p<0.003 after adjustment for family-wise error.

Results

Six-hundred and fifty-five respondents (292 ATs, 317 PTs, 46 dual credentialed PT/ATs) completed the entire survey. ATs had the highest level of perceived preparedness of all the groups (p<0.0005). Greater than 75% of PTs responded either "appropriately" or "overly cautious" to 10 of the 17 case scenarios, as opposed to 11 of the 17 case scenarios by ATs. Greater than 75% of the PTs who were board specialty certified in sports responded either "appropriately" or "overly cautious" to 13 case scenarios.

Conclusion

More ATs than PTs perceived themselves to be prepared to manage acute injuries/medical conditions. Further, results indicate that PTs may be an effective and safe provider of event coverage. Conditions/injuries with low perceived preparedness or poor performance...
may offer both ATs and PTs an opportunity to identify areas for future training and education to optimize care for athletes with acute injuries or medical conditions.

**Level of Evidence**

Level 3b

**BACKGROUND**

Over 7.9 million students participate in high school athletics. Having appropriate personnel, facilities, and plans for the emergency management and care of injuries sustained by student athletes is imperative for their safety and well-being. Injuries occur at a rate of 2.3 injuries per 1,000 athlete exposures in secondary school sports; however, there continues to be a lack of event coverage provided by qualified medical professionals to manage acute injury situations that may occur with student athletes across the country. Often a coach may be the person responsible for providing medical coverage during a practice or competition. Data from the Athletic Training Location and Services (ATLAS) database from 2018 showed 69% of public secondary schools and 55% of private secondary schools provide specific event coverage with athletic trainer (AT) services for their student-athletes. Of these, only 37% of public schools and 27% of private schools offered a full-time AT on an every-afternoon basis. Many factors have been identified related to a lack of ATs in these settings. Having additional qualified healthcare providers may limit this gap in coverage and support the health and safety of student-athletes.

Physical therapists (PTs) may also provide athletic event coverage. However, knowledge regarding the frequency and prevalence of PTs’ involvement in secondary school event coverage is limited. While ATs are specifically trained in acute sports injury management, there are educational areas of overlap between ATs and PTs. However, substantial differences in entry-level educational training exists between ATs and PTs. ATs receive education on providing immediate and emergency care for athletes suffering from acute injuries or medical conditions, while PT entry-level training typically lacks the content for emergency care of athletes in on-field or sideline situations. Some PTs do participate in specialized training through elective coursework and/or post-professional residencies and fellowships to obtain advanced, board specialty certification in sports (SCS) and training in the field of sports injury management.

However, despite both ATs and PTs providing event coverage, there is limited understanding of their perceived preparedness in the management of acute injuries and medical conditions. In addition, it is unknown how clinical decision-making and management of emergency situations by both ATs and PTs may differ. Lastly, there is a lack of understanding of which injuries or medical conditions certain medical professionals may struggle to manage. A better understanding of the above is necessary to be able to provide the best management for the healthcare needs of athletes.

The primary purpose of this study was to compare the perceived preparedness and decision-making skills related to acute injury and medical condition management by ATs and PTs. The secondary purpose was to evaluate the relationship between a provider’s perceived preparedness and responses on case scenarios focused on acute medical scenarios. The underlying rationale for this project was to better understand both perceived preparedness and clinical decision-making by both ATs and PTs. It was hypothesized that ATs would report greater perceived preparedness and choose more appropriate responses in the management of acute/emergency situations compared to PTs. Second, it was hypothesized that greater perceived preparedness would positively correlate to more appropriate injury management responses.

**METHODS**

**PARTICIPANTS**

This study was a cross-sectional design electronic exploratory survey study of licensed ATs and PTs in the state of Ohio during the 2019 calendar year. An e-mail database was obtained from the Ohio Occupational Therapy, Physical Therapy, and Athletic Trainers board. Current AT or PT students registered through the board were excluded from the data. Physical therapist assistants (PTA) that were not also credentialed as an AT or PT were also excluded.

**INSTRUMENTATION**

All participants completed an online questionnaire (QualtricsXM, Provo, UT) (Appendix A). The study utilized an adapted version of the survey developed by Cross and colleagues (with permission) which has been validated and previously used with high school coaches, PTs, and PT students. In addition to demographics, the survey included questions related to involvement in performing athletic event coverage, frequency of coverage, and coverage responsibilities. Participants were also asked to rate their perceived preparedness on a 5-point scale: “prepared (1),” “somewhat prepared (2),” “neutral (3),” “somewhat un-prepared (4),” “not prepared (5)” Participants were presented a set of case scenarios and were asked to determine what they believe to be an appropriate course of action for a particular medical situation. The scenarios were developed so that the participant needed to account for player type (starter/non-starter) and competition significance (important/non important competition). Each participant evaluated the case scenario and chose what they believed to be the appropriate course of action for the athlete. Participants chose one of four options: “hold out and refer” “hold out and monitor symptoms,” “return to competition and monitor,” or “return to competition and not monitor” (Figure 1) (Appendix A, Section 3). The correct/appropriate responses to these scenarios were determined and validated in a previous study by Cross et al.

The project and study protocol were reviewed, and permission to conduct the study was granted by The Ohio State University Institutional Review Board. Potential partici-
pants were provided a consent letter via e-mail and consented electronically prior to beginning their participation in the study.

DATA COLLECTION

Potential participants received an e-mail describing the study and a link to begin the survey. All potential participants were notified that their participation in the study was voluntary and that no incentive would be given for completion of the survey. Reminder emails were sent two and three weeks following the initial email. Only those participants that fully completed the perceived preparedness and case scenario sections were included in the analysis.

DATA ANALYSIS

Using an online sample size calculator, 95% confidence interval, 5% margin of error, and a population size of 9,888 PTs, and 2,985 ATs it was determined that a total of 374 surveys would need to be completed for the primary purpose.26 IBM SPSS Statistics Version 25 (SPSS, Inc, Chicago, IL) was used to analyze the data. Frequencies and descriptive statistics were used to analyze demographic information, perceived preparedness, and responses to the case scenarios.

Cross tabulations were used to analyze profession-specific responses for perceived preparedness and the case responses. For the primary purpose a Kruskal-Wallis H-Test for one-way analysis of the variance (ANOVA) was used to analyze the differences in distribution of the perceived preparedness between the ATs and PTs. As PTs who are board specialty certified in Sports (SCS-PTs) have specific training in acute injury management, a secondary preliminary analysis was also performed using a Kruskal-Wallis H-Test to compare ATs and SCS-PTs, and SCS-PTs and NonSCS-PTs. For the secondary purpose a Spearman’s Rho Correlation was used to determine if a correlation exists between a participant’s perceived preparedness and their ability to choose an appropriate decision regarding an athlete’s return to play or referral status. Values of correlation analysis were interpreted as poor (<0.25), fair (0.25-0.49), moderate to good (0.05-0.74), and good to excellent (>0.75).27 The categories from the perceived preparedness section were paired with the case study question that pertained to the similar medical condition to determine the correlation between a respondent’s answers. Data from participants that identified as dual-credentialed (AT/PT) were included in the demographic results; however, they were not included in the perceived preparedness and case scenario analysis as their results did not meet the aims of this study. A Sidak’s adjustment for multiple comparisons was made for each of the family-wise analyses accounting for the different comparisons or correlations. After the adjustment significance was set p≤0.003.

Similar to Cross and colleagues,10,23–25 the term “at least somewhat prepared” is used throughout the analysis, and indicates that a respondent replied as either "prepared" or "somewhat prepared".10,23 These two responses were pooled together at times during the analysis in that they indicate that a respondent feels comfortable managing the specific injury category with their current knowledge base and skill set. The responses to the case scenarios were graded as either “appropriate”, “inappropriate”, or “overly cautious”.25 In some instances during the case scenario section, a case had both a "most appropriate" response, and an “appropriate” response. In these instances, both answers were grouped together to form an “appropriate” response. An “appropriate” response indicates that the return to play decision provided by the medical professional was a safe decision for the health and well-being of the athlete. Lastly, 75% was used as a benchmark when comparing responses among the groups as the authors felt it would best represent a large majority of the respondents in each group to be able to compare results to previous literature.10,25

RESULTS

Of the 869 initial responses, 214 were removed for not meeting the inclusion criteria or for not completing 100% of the perceived preparedness questions and case scenarios. This resulted in a final sample size of 655 participants (5.0%) (Figure 2). The survey was completed by 292 ATs, 317 PTs, and 46 dual-credentialed providers (AT/PT) (Table 1). Seventy-three (20%) of the PT and AT/PT respondents had obtained specialty certification (e.g. Sports, Orthopedic, Geriatric, Neurology, Womens Health) through the American Boards of Physical Therapy Specialties (ABPTS) (Table 2). There were a total of 25 PTs (including dual credentialed PT/AT) who were SCS credentialed in the initial sample. Seventeen (5.4%) were PTs only and included in the final analysis. (Table 2). Further, 251 (86%) ATs indicated they provided sports event coverage whereas 22 (6.9%) of PTs indicated that they provided event coverage (Table 3) As part of the survey, the participants were asked which sports they considered to be their "primary" or "secondary" responsibilities. Responses indicated 26 different sports or events (Table 5).
Table 1. Demographic Data

<table>
<thead>
<tr>
<th>Category</th>
<th>n (%)</th>
<th>Category</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (n= 655)</td>
<td></td>
<td>Age (n= 654)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>244 (37.3)</td>
<td>Under 25</td>
<td>46 (7.0)</td>
</tr>
<tr>
<td>Female</td>
<td>405 (61.8)</td>
<td>25-29</td>
<td>146 (22.3)</td>
</tr>
<tr>
<td>Prefer not to Answer</td>
<td>6 (0.9)</td>
<td>30-34</td>
<td>118 (18.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>35-39</td>
<td>67 (10.2)</td>
</tr>
<tr>
<td>Profession (n= 655)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Athletic Trainer</td>
<td>292 (44.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical Therapist</td>
<td>317 (48.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AT/PT</td>
<td>46 (7.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Job duties more closely align with weekly (AT/PT Only) (n=46)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Athletic Trainer</td>
<td>8 (17.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical Therapist</td>
<td>38 (82.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highest Degree Earned (n= 654)</td>
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<td>Baccalaureate</td>
<td>175 (26.9)</td>
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<td></td>
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<tr>
<td>Master’s</td>
<td>268 (41.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAT</td>
<td>3 (0.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DPT (Entry-Level)</td>
<td>171 (26.1)</td>
<td></td>
<td></td>
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<tr>
<td>PhD (or equivalent)</td>
<td>23 (3.5)</td>
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<tr>
<td>Other</td>
<td>14 (2.1)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Full-time salaried</td>
<td>417 (63.7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Part-time salaried</td>
<td>32 (5.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Full-time hourly</td>
<td>104 (15.8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Part-time hourly</td>
<td>64 (9.7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Full-time self-employed</td>
<td>13 (2.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Part-time self-employed</td>
<td>8 (1.2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unemployed</td>
<td>6 (0.9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not working (retired)</td>
<td>11 (1.7)</td>
</tr>
<tr>
<td>AT Primary Practice Setting (n= 304)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary School</td>
<td>124 (40.8)</td>
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<td></td>
</tr>
<tr>
<td>2-Year Institution</td>
<td>5 (1.6)</td>
<td></td>
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</tr>
<tr>
<td>4-Year Institution</td>
<td>77 (25.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outpatient/Rehabilitation/ Ambulatory Clinic</td>
<td>25 (8.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hospital System or physician’s office</td>
<td>41 (13.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Professional Sports</td>
<td>7 (2.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industry</td>
<td>5 (1.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>20 (6.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PT Primary Practice Setting (n= 351)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Hospital system or hospital based OP facility</td>
<td></td>
<td></td>
<td>157 (44.7)</td>
</tr>
<tr>
<td>Acute care hospital</td>
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<td></td>
<td>29 (8.3)</td>
</tr>
<tr>
<td>Subacute rehab hospital</td>
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<td></td>
<td>17 (4.8)</td>
</tr>
<tr>
<td>Private OP or group practice</td>
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<td></td>
<td>66 (18.8)</td>
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<tr>
<td>Academic Institution</td>
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<td></td>
<td>23 (6.6)</td>
</tr>
<tr>
<td>Health and wellness facility</td>
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<td></td>
<td>4 (1.1)</td>
</tr>
<tr>
<td>Industry</td>
<td></td>
<td></td>
<td>2 (0.6)</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td>53 (15.1)</td>
</tr>
</tbody>
</table>

COMPARISON OF PERCEIVED PREPAREDNESS

Over 75% of all the participants claimed to be either "prepared" or "somewhat prepared" to manage 15 of the 16 injuries and medical conditions (Table 4). At least 75% of ATs responded that they felt "prepared" to respond to an athlete with nine of the 16 conditions (Table 4) while approximately 75% of PTs felt "prepared" for sprains and strains. Over 75% of ATs felt at least "somewhat prepared" for all 16 of the injuries and medical conditions, while over 75% of PT’s felt at least "somewhat prepared" for five of the 16 injuries and medical conditions. The distribution of perceived preparedness responses were different for all 16 conditions when comparing ATs and PTs, with a greater percentage of ATs reporting they were "Prepared" for all 16 of the categories compared to the PTs (Figure 3 and Table 4).

At least 75% of the SCS-PTs responded as being at least "somewhat prepared" for 14 of the 16 categories, excluding concussion and asthma attacks (Appendix B - Table 8). When comparing the distribution between ATs and SCS-PT’s responses regarding perceived preparedness, the responses were significantly different for four of the 16 categories (concussion, open wounds, asthmas, and head injury). Finally, at least 75% of NonSCS-PTs answered that they were at least somewhat prepared for four of the 16 categories. When comparing the distribution between the SCS-
Table 2. Professional Practice and Certification Information

<table>
<thead>
<tr>
<th>Category</th>
<th>n (%)</th>
<th>Category</th>
<th>n (%)</th>
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</thead>
<tbody>
<tr>
<td>Years of Practice (n= 654)</td>
<td></td>
<td>Years in current position (n= 649)</td>
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<tr>
<td>&lt;1</td>
<td>34 (5.2)</td>
<td>&lt; 1</td>
<td>104 (16.0)</td>
</tr>
<tr>
<td>1-3</td>
<td>106 (16.2)</td>
<td>1-3</td>
<td>206 (31.7)</td>
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<tr>
<td>4-5</td>
<td>61 (9.3)</td>
<td>4-5</td>
<td>77 (11.9)</td>
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<td>6-10</td>
<td>118 (18.0)</td>
<td>6-10</td>
<td>94 (14.5)</td>
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<td>11-15</td>
<td>62 (9.5)</td>
<td>11-15</td>
<td>68 (10.5)</td>
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<td>16-20</td>
<td>80 (12.2)</td>
<td>16-20</td>
<td>36 (5.5)</td>
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<tr>
<td>21-30</td>
<td>105 (16.1)</td>
<td>21-30</td>
<td>49 (7.6)</td>
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<td>31+</td>
<td>88 (13.5)</td>
<td>31+</td>
<td>15 (2.3)</td>
</tr>
<tr>
<td>Graduated from ABPTRFE program (PT AT/PT Only) (n= 73)</td>
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<td>ABPTS Board specialization (PT AT/PT Only) (n= 363)</td>
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<tr>
<td>Yes</td>
<td>18 (24.6)</td>
<td>Yes</td>
<td>73 (20.1)</td>
</tr>
<tr>
<td>No</td>
<td>55 (75.3)</td>
<td>No</td>
<td>290 (79.9)</td>
</tr>
<tr>
<td>ABPTS Specialization Certification (PT AT/PT Only) (n= 73)</td>
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<td>Additional Certifications (n= 655)</td>
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</tr>
<tr>
<td>Sports</td>
<td>23 (31.5)</td>
<td>ACLS</td>
<td>37 (5.6)</td>
</tr>
<tr>
<td>Orthopedic</td>
<td>36 (49.3)</td>
<td>Paramedic</td>
<td>3 (0.5)</td>
</tr>
<tr>
<td>Orthopedic Manual</td>
<td>4 (5.4)</td>
<td>EMT</td>
<td>11 (1.7)</td>
</tr>
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<td>Geriatric</td>
<td>7 (9.5)</td>
<td>First Responder</td>
<td>59 (9.0)</td>
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<td>Neurology</td>
<td>5 (6.8)</td>
<td>Personal Trainer</td>
<td>6 (0.9)</td>
</tr>
<tr>
<td>Women’s health</td>
<td>1 (1.3)</td>
<td>CSCS</td>
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<td>PES</td>
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<td></td>
<td></td>
<td>Other</td>
<td>147 (22.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>None</td>
<td>110 (16.7)</td>
</tr>
</tbody>
</table>

AT= Athletic Trainer; PT= Physical Therapist; AT/PT= Dual credentialed athletic trainer and physical therapist; ABPTRFE=American Board of Physical Therapy Residency and Fellowship Education; ABPTS= American Board of Physical Therapy Specialties; ACLS= Advanced Cardiovascular Life Support; EMT= Emergency Medical Technician; CSCS= Certified Strength and Conditioning Specialist; PES= Performance Enhancement Specialist

Flow Diagram of Sampling Procedures

Figure 2. Flow Diagram of Sampling Procedures.

OTPTAT = State of Ohio Occupational Therapy, Physical Therapy, and Athletic Trainers Board. The survey was only sent to Physical Therapists and Athletic Trainers. Average Percent Perception of Perceived Preparedness for Athletic Trainers and Physical Therapists. Seventy-seven percent of the Athletic Trainers felt "Prepared" while only 34% of the Physical Therapists felt prepared. Nineteen percent of the Athletic Trainers felt "Somewhat Prepared" vs. 35% of the Physical Therapists. Three percent of the Athletic Trainers and 13% of the Physical Therapists felt "Neutral." While only 1% of the Athletic Trainers felt "Somewhat Underprepared" vs. 10% of the Physical Therapists. Finally, less than 1% (0.12%) of the Athletic Trainers felt "Not Prepared" compared to 8% of the Physical Therapists. These results suggest that Physical Therapists felt less prepared to management acute injury situations than Athletic Trainers. More specific results are presented in Table 4.

PTs and the NonSCS-PTs responses regarding perceived preparedness, the responses were different for four of the 16 categories (dislocations, fractures, heat stroke, and internal organs) (Appendix B - Table 11) with a greater percentage of SCS-PTs reporting they were at least "somewhat prepared" for all 16 of the categories compared to the NonSCS-PTs.
Table 3. Athletic Trainer and Physical Therapist Event Coverage Data

<table>
<thead>
<tr>
<th>Category</th>
<th>AT n (%)</th>
<th>PT n (%)</th>
<th>Category</th>
<th>AT n (%)</th>
<th>PT n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage for Sporting Events (n= 609)</td>
<td></td>
<td></td>
<td>Frequency of Sporting Event Coverage (n= 273)</td>
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<tr>
<td>Yes</td>
<td>251 (86.0)</td>
<td>22 (6.9)</td>
<td>4-6 times a week</td>
<td>199 (79.3)</td>
<td>1 (4.5)</td>
</tr>
<tr>
<td>No</td>
<td>41 (14.0)</td>
<td>295 (93.1)</td>
<td>2-3 times a week</td>
<td>23 (9.2)</td>
<td>6 (27.3)</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>Once a week</td>
<td>7 (2.8)</td>
<td>1 (4.5)</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>Once a month</td>
<td>10 (4.0)</td>
<td>4 (18.2)</td>
</tr>
<tr>
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<td>Every other month</td>
<td>5 (2.0)</td>
<td>4 (18.2)</td>
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<td></td>
<td>Once every three months</td>
<td>5 (2.0)</td>
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<tr>
<td></td>
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<td>Twice a year</td>
<td>1 (0.4)</td>
<td>3 (13.6)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Once a year</td>
<td>1 (0.4)</td>
<td>0 (0.0)</td>
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</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>n (%)</th>
<th>Category</th>
<th>n (%)</th>
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<tbody>
<tr>
<td>Primary Sport Responsibility (n= 278)</td>
<td></td>
<td>Secondary Sport Responsibility (n= 246)</td>
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<tr>
<td>All</td>
<td>13 (4.6)</td>
<td>All</td>
<td>12 (4.8)</td>
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<td>Baseball</td>
<td>19 (6.8)</td>
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<td>5 (1.8)</td>
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<tr>
<td>Basketball</td>
<td>15 (5.4)</td>
<td>Basketball</td>
<td>73 (26.5)</td>
</tr>
<tr>
<td>Community Events</td>
<td>5 (1.8)</td>
<td>Community Events</td>
<td>9 (3.3)</td>
</tr>
<tr>
<td>Cross Country</td>
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<td>Cross Country</td>
<td>4 (1.5)</td>
</tr>
<tr>
<td>Fencing</td>
<td></td>
<td>Fencing</td>
<td>1 (0.4)</td>
</tr>
<tr>
<td>Field Hockey</td>
<td>1 (0.4)</td>
<td>Field Hockey</td>
<td>3 (1.1)</td>
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<td>Football</td>
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<td>Football</td>
<td>9 (3.3)</td>
</tr>
<tr>
<td>Golf</td>
<td></td>
<td>Golf</td>
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<td>Gymnastics</td>
<td>1 (0.4)</td>
<td>Gymnastics</td>
<td>3 (1.1)</td>
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<td>Ice Hockey</td>
<td>10 (3.6)</td>
<td>Ice Hockey</td>
<td>6 (2.2)</td>
</tr>
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<td>Lacrosse</td>
<td>8 (2.9)</td>
<td>Lacrosse</td>
<td>16 (5.8)</td>
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<td>Rugby</td>
<td>3 (1.1)</td>
<td>Rugby</td>
<td>5 (1.8)</td>
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<td>35 (12.6)</td>
<td>Soccer</td>
<td>41 (14.9)</td>
</tr>
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<td>Swimming/Diving</td>
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<tr>
<td>Tennis</td>
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<td>Tennis</td>
<td>5 (1.8)</td>
</tr>
<tr>
<td>Track and Field</td>
<td>3 (1.1)</td>
<td>Track and Field</td>
<td>17 (6.2)</td>
</tr>
<tr>
<td>Wrestling</td>
<td>3 (1.1)</td>
<td>Wrestling</td>
<td>9 (3.3)</td>
</tr>
<tr>
<td>Volleyball</td>
<td>7 (2.5)</td>
<td>Volleyball</td>
<td>6 (2.2)</td>
</tr>
<tr>
<td>Other</td>
<td>13 (4.6)</td>
<td>Other</td>
<td>6 (2.2)</td>
</tr>
</tbody>
</table>

AT = Athletic Trainer; PT = Physical Therapist

Comparisons of Responses to Acute Case Scenarios

Responses for nine out of the 17 cases were different when comparing the ATs and PTs and responses to the acute case scenarios (Table 5 and Figure 4). ATs provided more “inappropriate” than “appropriate” responses for three of the case scenarios: neck injury, second concussion, and dislocation. PTs had more “appropriate” than “inappropriate” responses. Greater than 75% of ATs responded either “appropriately” or “overly cautious” to 11 case scenarios while greater than 75% of PTs responded “appropriately” or “overly cautious” to nine case scenarios (Table 5). In addition, a greater percentage (p≤0.003) of ATs provided the “Most Appropriate” answer on six of the 17 cases compared to the PTs (asthma, first concussion, fracture, heat stroke, ankle sprain, and internal organ) whereas a greater percentage of PTs provided the “Most Appropriate” answer for only three of the 17 cases (dehydration, cardiac arrest, and second concussion) compared to the ATs (Table 5). Further, a greater percentage of ATs provided the “Most Appropriate” answer on one case (spinal cord injury) when compared to the SCS-PTs while the SCS-PTs did not provide more “Most Appropriate” answers when compared to the ATs (Appendix B – Table 9). No case scenarios were different when comparing SCS-PTs and NonSCS-PTs (Appendix B- Table 12). However, these results should be interpreted with caution as this sub-analysis is likely underpowered for sub-analysis. The NonSCS-PT group had zero instances where the majority of respondents answered the case scenarios incorrectly.
Table 4. Athletic Trainers and Physical Therapist’s Perceived Preparedness

<table>
<thead>
<tr>
<th>Condition</th>
<th>Prepared n (%)</th>
<th>Somewhat Prepared n (%)</th>
<th>Neutral n (%)</th>
<th>Somewhat Unprepared n (%)</th>
<th>Not Prepared n (%)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AT</td>
<td>PT</td>
<td>AT</td>
<td>PT</td>
<td>AT</td>
<td>PT</td>
</tr>
<tr>
<td>Concussions</td>
<td>279 (95.5)</td>
<td>74 (23.3)</td>
<td>10 (3.4)</td>
<td>124 (39.1)</td>
<td>2 (0.7)</td>
<td>41 (12.9)</td>
</tr>
<tr>
<td>Dislocations</td>
<td>190 (65.1)</td>
<td>66 (20.7)</td>
<td>86 (29.5)</td>
<td>101 (31.9)</td>
<td>12 (4.1)</td>
<td>53 (16.7)</td>
</tr>
<tr>
<td>Fatigue/Dehydration</td>
<td>260 (89.0)</td>
<td>124 (38.9)</td>
<td>31 (10.6)</td>
<td>117 (36.9)</td>
<td>1 (0.3)</td>
<td>44 (13.9)</td>
</tr>
<tr>
<td>Fractures</td>
<td>247 (84.6)</td>
<td>108 (34.1)</td>
<td>42 (14.4)</td>
<td>121 (38.2)</td>
<td>3 (1.0)</td>
<td>33 (10.4)</td>
</tr>
<tr>
<td>Open Wounds</td>
<td>276 (94.5)</td>
<td>99 (31.2)</td>
<td>15 (5.1)</td>
<td>123 (38.8)</td>
<td>0</td>
<td>44 (13.9)</td>
</tr>
<tr>
<td>Sprains</td>
<td>292 (100)</td>
<td>237 (74.8)</td>
<td>0</td>
<td>68 (21.5)</td>
<td>0</td>
<td>7 (2.2)</td>
</tr>
<tr>
<td>Strains</td>
<td>291 (99.7)</td>
<td>238 (75.1)</td>
<td>1 (0.3)</td>
<td>61 (19.2)</td>
<td>0</td>
<td>11 (3.5)</td>
</tr>
<tr>
<td>Asthma Attacks</td>
<td>209 (71.6)</td>
<td>47 (14.8)</td>
<td>73 (25.0)</td>
<td>121 (38.2)</td>
<td>8 (2.7)</td>
<td>63 (19.9)</td>
</tr>
<tr>
<td>Cardiac Arrest</td>
<td>216 (74.0)</td>
<td>149 (47.0)</td>
<td>67 (22.9)</td>
<td>112 (35.3)</td>
<td>6 (2.0)</td>
<td>32 (10.1)</td>
</tr>
<tr>
<td>Head Injury</td>
<td>263 (90.1)</td>
<td>82 (25.9)</td>
<td>26 (8.9)</td>
<td>121 (38.2)</td>
<td>3 (1.0)</td>
<td>53 (16.7)</td>
</tr>
<tr>
<td>Heat Stroke</td>
<td>228 (78.1)</td>
<td>70 (22.1)</td>
<td>60 (20.5)</td>
<td>118 (37.2)</td>
<td>3 (1.0)</td>
<td>54 (17.0)</td>
</tr>
<tr>
<td>Neck Injuries</td>
<td>231 (79.1)</td>
<td>114 (36.0)</td>
<td>54 (18.5)</td>
<td>115 (36.3)</td>
<td>4 (1.4)</td>
<td>37 (11.7)</td>
</tr>
<tr>
<td>Seizures</td>
<td>161 (55.1)</td>
<td>88 (27.8)</td>
<td>102 (34.9)</td>
<td>123 (38.8)</td>
<td>24 (8.2)</td>
<td>50 (15.8)</td>
</tr>
<tr>
<td>Spinal Cord</td>
<td>207 (70.9)</td>
<td>75 (23.7)</td>
<td>67 (22.9)</td>
<td>129 (40.7)</td>
<td>14 (4.8)</td>
<td>43 (13.6)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>153 (52.4)</td>
<td>139 (43.8)</td>
<td>118 (40.4)</td>
<td>109 (34.4)</td>
<td>17 (5.8)</td>
<td>34 (10.7)</td>
</tr>
<tr>
<td>Internal Organs</td>
<td>86 (29.5)</td>
<td>20 (6.3)</td>
<td>148 (50.7)</td>
<td>96 (30.3)</td>
<td>42 (14.4)</td>
<td>68 (21.5)</td>
</tr>
</tbody>
</table>

AT= Athletic Trainer; PT= Physical Therapists *p≤0.003
CORRELATION BETWEEN PERCEIVED PREPAREDNESS AND APPROPRIATENESS

When examining whether perceived preparedness was correlated to "appropriate" answers on the cases, the ATs and PTs responses were initially pooled together. Results demonstrated significant, yet poor relationships for the case involving dehydration ($\rho = -0.14; p=0.001$). Each of the groups were explored separately as a secondary analysis. There was a positive weak correlation between perceived preparedness and "appropriate" response for the case involving a first concussion ($\rho = 0.27; p<0.001$) for the ATs (Table 6). There were no correlations between perceived preparedness and "appropriate" response for PTs, SCS-PTs, or NonSCS-PTs (Table 7, Appendix B - Tables 10 and 15). However, these results should be interpreted with caution as this secondary analysis was likely underpowered.

DISCUSSION

This is the first study to examine both ATs' and PTs' perceived preparedness to manage acute athletic injuries, as well as their ability to appropriately manage emergency situations using case scenarios. All participants perceived themselves to be the least prepared to manage athletes suffering from an injury to an internal organ (58.8%), dislocation (74.4%), and an asthma attack (75%). Cross and colleagues findings indicated that their participants felt least prepared to manage internal organ (56.7%), seizures (66.9%) and spinal cord injury (72.7%). In the current study, ATs perceived themselves to be more prepared for the management of acute injuries and medical conditions compared to PTs, as well as SCS-PTs. However, SCS-PTs had a higher reported perceived preparedness in comparison to their NonSCS-PT colleagues.

Similar to Cross and colleagues, the four cases with the highest "inappropriate" responses for PTs were neck injury (43.2% "inappropriate"), dislocation (42% "inappropriate"), 2nd concussion (40.4% "inappropriate") and knee sprain (38.8% "inappropriate"). Similarly ATs had the highest number of "inappropriate" responses to the cases pertaining to neck injury (54.1% "inappropriate"), dislocation (52.1% "inappropriate") and second concussion (51% "inappropriate"). NonSCS-PTs provided the most "overly-cautious" responses to the case scenarios, but were the only group that did not have a majority "inappropriate" response to a case scenario.
Table 5. Athletic Trainers and Physical Therapist’s Responses to Case Scenarios

<table>
<thead>
<tr>
<th>Question &amp; Scenario</th>
<th>Hold Out &amp; Refer n (%)</th>
<th>Hold Out &amp; Monitor n (%)</th>
<th>Return &amp; Monitor n (%)</th>
<th>Return &amp; Not Monitor n (%)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AT</td>
<td>PT</td>
<td>AT</td>
<td>PT</td>
<td></td>
</tr>
<tr>
<td>1. Dehydration</td>
<td>160 (54.8)^A</td>
<td>242 (76.3)^A</td>
<td>131 (44.9)</td>
<td>73 (23.0)</td>
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</tr>
<tr>
<td>2. Asthma</td>
<td>0^O</td>
<td>1 (0.3)</td>
<td>10 (3.4)</td>
<td>31 (9.8)</td>
<td></td>
</tr>
<tr>
<td>3. Cardiac Arrest</td>
<td>206 (70.5)^A</td>
<td>263 (83.0)^A</td>
<td>83 (28.4)</td>
<td>52 (16.4)</td>
<td></td>
</tr>
<tr>
<td>4. 1st Concussion</td>
<td>43 (14.7)^A</td>
<td>99 (31.2)^A</td>
<td>248 (84.9)^A</td>
<td>216 (68.1)^A</td>
<td></td>
</tr>
<tr>
<td>5. Neck Injury</td>
<td>134 (45.9)^A</td>
<td>180 (56.8)^A</td>
<td>133 (45.5)</td>
<td>111 (35.0)</td>
<td></td>
</tr>
<tr>
<td>6. Diabetes</td>
<td>1 (0.3)</td>
<td>2 (0.6)</td>
<td>7 (2.4)</td>
<td>16 (5.0)</td>
<td></td>
</tr>
<tr>
<td>7. Fracture</td>
<td>141 (48.1)^A</td>
<td>198 (62.5)^A</td>
<td>140 (47.9)^A</td>
<td>116 (36.6)^A</td>
<td></td>
</tr>
<tr>
<td>8. Spinal Cord Injury</td>
<td>233 (79.8)^A</td>
<td>237 (74.1)^A</td>
<td>57 (19.5)</td>
<td>79 (24.9)</td>
<td></td>
</tr>
<tr>
<td>9. Head Injury</td>
<td>234 (80.1)^A</td>
<td>230 (72.6)^A</td>
<td>58 (19.9)</td>
<td>77 (24.1)</td>
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<tr>
<td>10. Knee Sprain</td>
<td>2 (0.7)</td>
<td>1 (0.3)</td>
<td>21 (7.2)</td>
<td>19 (6.0)</td>
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</tr>
<tr>
<td>11. 2nd Concussion</td>
<td>3 (1.0)</td>
<td>15 (4.7)</td>
<td>140 (47.9)^A</td>
<td>174 (54.9)^A</td>
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<tr>
<td>12. Dislocation</td>
<td>8 (2.7)</td>
<td>17 (5.4)</td>
<td>132 (45.2)^A</td>
<td>167 (52.7)^A</td>
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<td>13. Heat Exhaustion</td>
<td>23 (7.9)</td>
<td>28 (8.8)</td>
<td>258 (88.4)^A</td>
<td>277 (87.4)^A</td>
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</tr>
<tr>
<td>14. Heat Stroke</td>
<td>249 (85.3)^A</td>
<td>236 (74.4)^A</td>
<td>42 (14.4)</td>
<td>79 (24.9)</td>
<td></td>
</tr>
<tr>
<td>15. Ankle Sprain</td>
<td>0^O</td>
<td>0^O</td>
<td>40 (13.7)</td>
<td>87 (27.4)^A</td>
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</tr>
<tr>
<td>16. Eye Injury</td>
<td>263 (90.1)^A</td>
<td>271 (85.5)^A</td>
<td>28 (9.6)</td>
<td>43 (13.6)</td>
<td></td>
</tr>
<tr>
<td>17. Internal Organ</td>
<td>256 (87.7)^A</td>
<td>230 (72.6)^A</td>
<td>35 (12.0)</td>
<td>84 (26.5)</td>
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</tr>
</tbody>
</table>

*A= Most Appropriate Answer; A= Appropriate; I=Inappropriate; O= Overly Cautious
*p<0.003
Findings from this study may support focused education of both ATs and PTs who provide event coverage in particular regarding injuries or conditions that individuals perceive to be less prepared to manage and/or with scenarios. Further, there is limited entry-level training in acute sports injury management for PTs. Mulligan and DeVahl surveyed 241 entry-level PT education programs and only 45% of the responding programs indicated that they offered some form of sports physical therapy coursework. Further, only 52% of the programs discussed management of life-threatening emergencies and only 9% of the courses focused on athletic injury prevention. This combined with the current study findings suggest that if PTs desire to participate in event coverage then additional training (either in entry-level programs or with post-professional educational opportunities) may be important to best prepare them to appropriately manage acute athletic injuries as part of the sports medicine team. Specifically, PTs interested in working directly with the athletic population may participate in a sports physical therapy residency and/or related sub-subspecialty area fellowships through the American Board of Physical Therapy Residency and Fellowship Education. These post-professional education programs provide didactic and “on-the-job” mentoring and training in the care and management of athletes in the clinic and during sporting events as well as emergency management of athletes. Further, PTs (with or without sports residency training) may also obtain the SCS credential through the American Board of Physical Therapy Specialties. This credential indicates that PTs who are SCS have extensive knowledge in the rehabilitation and management of acute injuries and illnesses, medical/surgical considerations, injury prevention, sports performance enhancement, and professional roles and responsibilities in an athletic/sports population. Additionally, SCS-PTs are required to have direct sports event coverage and have passed emergency responder training in order to obtain and maintain specialty certification.

Finally, poor to no correlations were identified between a provider’s perceived preparedness and their ability to appropriately respond to acute injury scenarios in written cases. Thus, higher levels of perceived preparedness did not relate to more “appropriate” responses for the case scenarios. This is consistent in other studies examining self-perception of performance and actual performance in medicine. This disconnect between self-perception of preparedness and case scenarios responses suggests there may be a need to for practitioners to be more mindful in practical situations, reflect on their performance, and obtain objective feedback.
### Table 6. Athletic Trainer’s Preparedness vs Appropriateness

<table>
<thead>
<tr>
<th>Question</th>
<th>Decision</th>
<th>Prepared n (%)</th>
<th>Somewhat Prepared n (%)</th>
<th>Neutral n (%)</th>
<th>Somewhat Unprepared n (%)</th>
<th>Not Prepared n (%)</th>
<th>Spearman</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Dehydration</td>
<td>A</td>
<td>144 (90.0)</td>
<td>15 (9.4)</td>
<td>1 (0.6)</td>
<td></td>
<td></td>
<td>0.03</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>116 (87.9)</td>
<td>16 (12.1)</td>
<td></td>
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<td></td>
<td>OC</td>
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<tr>
<td></td>
<td>(n= 292)</td>
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<td></td>
</tr>
<tr>
<td>2. Asthma</td>
<td>A</td>
<td>192 (71.1)</td>
<td>68 (25.2)</td>
<td>8 (3.0)</td>
<td>2 (0.7)</td>
<td></td>
<td>-0.04</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>10 (83.3)</td>
<td>2 (16.7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OC</td>
<td>7 (70.0)</td>
<td>3 (30.0)</td>
<td></td>
<td></td>
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<td>(n= 292)</td>
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</tr>
<tr>
<td>3. Cardiac Arrest</td>
<td>A</td>
<td>153 (74.3)</td>
<td>48 (23.3)</td>
<td>2 (1.0)</td>
<td>2 (1.0)</td>
<td>1 (0.5)</td>
<td>0.02</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>63 (73.3)</td>
<td>19 (22.1)</td>
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<td>4 (4.7)</td>
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<tr>
<td></td>
<td>OC</td>
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<tr>
<td></td>
<td>(n= 292)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4. 1st Concussion</td>
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A= Appropriate; I=Inappropriate; OC= Overly Cautious
*p<0.003
## Table 7. Physical Therapist’s Preparedness vs Appropriateness

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<td>65 (21.7)</td>
<td>7 (2.3)</td>
<td>1 (0.3)</td>
<td>2 (0.7)</td>
<td>0.03</td>
<td>0.65</td>
</tr>
<tr>
<td>(n= 317)</td>
<td>I</td>
<td>13 (72.2)</td>
<td>3 (16.7)</td>
<td>1 (5.6)</td>
<td>1 (5.6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Eye Injury</td>
<td>A</td>
<td>69 (25.5)</td>
<td>103 (38.0)</td>
<td>46 (17.0)</td>
<td>29 (10.7)</td>
<td>24 (8.9)</td>
<td>-0.04</td>
<td>0.51</td>
</tr>
<tr>
<td>(n= 317)</td>
<td>I</td>
<td>13 (28.3)</td>
<td>18 (39.1)</td>
<td>7 (15.2)</td>
<td>7 (15.2)</td>
<td>1 (2.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Internal Organ</td>
<td>A</td>
<td>13 (5.7)</td>
<td>71 (30.9)</td>
<td>51 (22.2)</td>
<td>41 (17.8)</td>
<td>55 (23.5)</td>
<td>-0.03</td>
<td>0.61</td>
</tr>
<tr>
<td>(n= 317)</td>
<td>I</td>
<td>7 (8.0)</td>
<td>25 (28.7)</td>
<td>17 (19.5)</td>
<td>25 (28.7)</td>
<td>13 (14.9)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A= Appropriate; I=Inappropriate; OC= Overly Cautious

*International Journal of Sports Physical Therapy*
LIMITATIONS AND FUTURE RESEARCH

There were several limitations to this study. First, the sample consisted of licensed ATs and PTs in the state of Ohio and cannot be presumed to represent the entire United States or other countries. This study utilized cases that required a participant to choose between four options, while in a real-life scenario a medical professional may have additional options to determine an athlete’s return to play or need for referral. Further, there may have been flaws in the survey/scenarios that were not known. However, it was expected that any major flaws of issue were addressed during the survey validation by Cross et al. In addition, survey fatigue may have impacted participants focus. Further, in the survey it was not delineated if the ATs or PTs who provided event coverage in their current position were the sole provider of event coverage. Understanding this may have offered insight into the depth of event coverage experience of the respondents. Further, a low percentage (6.9%) of PTs who responded to the survey indicated they provided event coverage. Thus, there is likely a low potential for selection bias of PTs who have event coverage experience within the study sample. A sample of PTs with more or less exposure to event coverage may have responded differently to the survey and cases. Lastly, the SCS PTs comprised a small subgroup of the ABPTS credentialed PTs in the sample and the analysis was not powered to fully examine their responses. Thus, results should be interpreted cautiously. However, the percentage of SCS PTs (5.4%) within the sample was greater than the total percentage of physical therapists with the SCS credential in the United States (1%).

Although dual credentialed providers (PT/AT) were excluded from the analysis due to potential confounding, comparing their responses to those of the other groups may provide insight into how such background and experience influence perceived preparedness and decision-making. Future research should be conducted on a sample beyond one state to improve generalizability and/or to identify variations across the United States. Furthermore, a qualitative examination would allow insight on the thought process of whether to refer, return, monitor, or take additional action for an injured athlete. Lastly, examining of real-time practical situations may provide additional insights into the decision-making process and other external factors that may influence provider responses.

CONCLUSION

Overall, ATs had a high level of perceived preparedness whereas PTs overall had a low perceived level of preparedness regarding the management of some acute injuries and medical conditions. Further, both ATs and PTs overall performed well on acute injury case scenarios, yet SCS-PTs performed better than NonSCS-PTs on select scenarios. While ATs are commonly the providers of event coverage for sporting events, PTs that are interested in event coverage should be encouraged to seek out additional training/mentoring opportunities (e.g., entry-level opportunities, post-professional residency training, continuing education courses, etc.) to increase their perceived preparedness for the management of acute injuries and medical conditions. Further, conditions/injuries with low perceived preparedness or poor performance may offer both ATs and PTs an opportunity to identify areas for future training and education to optimize care for athletes with acute injuries or medical conditions.

IRB STATEMENT

This study was approved through the Institutional Review Board at The Ohio State University within the exempt research category.

CONFLICTS OF INTEREST/DISCLOSURE

Alan Wallace declares relevant financial activities outside of submitted work with payments made to him by his current employer (Kent State University).

Matthew Briggs declares relevant financial activities outside the submitted work with payments made to him by his current employer (The Ohio State University Wexner Medical Center) and Allied Health Education LLC; grant/grants pending paid to his employer by the National Institutes of Health, Ohio Physical Therapy Association, and American Physical Therapy Academy of Physical Therapy Education for support for unrelated projects; and travel/accommodations/meeting expenses unrelated to this project by the American Board of Physical Therapy Specialties.

James Onate declares board membership and ownership of stock/stock options with Human Elements.

John Dewitt no disclosure or conflicts of interest

Laurie Rinehart-Thompson no disclosure or conflicts of interest

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SUPPLEMENTARY MATERIALS

Appendix A

Appendix B
Original Research

Sport Specialization, Physical Performance and Injury History in Canadian Junior High School Students

Chris Whatman, PT, PhD°C, Carla van den Berg, MSc©, Luz Palacios-Derflingher, PhD©, Carolyn Emery, PhD©

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Keywords: physical performance, athletic, injury, youth, sport specialization

https://doi.org/10.26603/001c.29590

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Background
Youth sports participation is encouraged for proposed physical and psychological benefits. However, early sport specialization and the potentially negative consequences may be a cause for concern.

Purpose
To describe sport specialization in Canadian youth and investigate associations with previous injury and physical performance.

Study design
Cross-sectional study.

Methods
Junior high school students (grades 7-9, ages 11-16) were invited to participate. All participants completed a questionnaire capturing specialization level (low, moderate, high; based on year-round training, exclusion of other sports, and single-sport training) and injury history in the previous 12-months. Additionally, all participants completed physical performance measures including vertical jump (cm), predicted VO2max (mL/kg/min), single-leg balance (secs) and Y-Balance composite score (%). Logistic regression examined the association between school grade, school size, sex and sport specialization (Objective 1) and the association between sport specialization and injury history (Objective 2). Multivariable linear regression analyses (4) assessed associations between sport specialization category and physical performance measures (Objective 3).

Results
Two hundred and thirty-eight students participated in the study. Eighteen percent of participants reported high specialization, with no significant associations between sex, grade or school size and specialization category. There was no significant difference in the odds of sustaining previous injury between participants reporting moderate (OR=1.94, 95% CI 0.86-4.35) or high (OR=2.21, 95% CI 0.43-11.37) compared to low specialization. There were no significant differences in vertical jump height (mean diff [MD] = -0.4 to 2.1cm), predicted VO2max (MD = 2.2 to 3.1mL/kg/min), single leg balance (MD = 0.5 to 1.9sec) or Y-balance (MD = 0.6 to 7.0%) between sport specialization.

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Faculty of Health and Environmental Sciences
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Northcote, Auckland 0627,
New Zealand
categories.

Conclusions

Sport specialization exists in Canadian junior high schools but may be less common than previously reported and it was not associated with sex, grade, or school size. Level of specialization was not associated with history of injury nor a range of physical performance measures.

Level of Evidence

Level 3

INTRODUCTION

Participation in youth sport, centered on recreational and fun activities, offers many physical and psychological benefits. However, recent trends in youth sport have seen less emphasis on recreation and increased focus on specialization in a single sport with more importance on competition and success. While there is no universally accepted definition, sport specialization generally relates to intense, year-round competition in a single sport at the exclusion of other sports. The push for greater specialization is linked to the belief of some coaches and parents that it is more likely to lead to high school and adult sport successes. However, much debate remains as to whether early specialization is needed in most youth sports. Early sampling of many sports, with gradual specialization in later adolescence, is thought more likely to lead to later success. Additionally, several expert groups have advised against early specialization due to concerns regarding increased injury risk and burnout.

The increased injury risk with specialization is potentially related to repetitive homogenous loads experienced when performing repetitive movement patterns in a single sport. In a study including American high school athletes, students rated as medium to high specialization were two to four times more likely to sustain a gradual onset or recurrent injury than athletes rated as low specialization. Similarly, in a large retrospective study including children and adolescents attending a sports medicine clinic for a sport-related injury, high specialization was an independent risk factor for serious overuse injury but not acute injury. In contrast, McGowen et al. studied early specialization and found no independent association between high specialization and injury history. Two recent systematic reviews concluded there is evidence that a link exists between specialization and sports related injury, however this evidence is limited to a small number of studies.

Early specialization may also lead to increased injury risk due to a reduction in the range of motor skills developed. The development of diverse motor skills is fostered when parents and educators facilitate opportunities for free unstructured play and involvement in a variety of sports. By engaging in a wide variety of sports youth are exposed to a greater range of strength, flexibility and balance challenges which may improve neuromuscular development and thus reduce injury risk. Single sport male high school athletes have been reported to perform worse than multisport athletes on the Y-Balance test. Poor performance on balance testing has been linked to increased risk of lower extremity injury.

There is little evidence as to the levels of sport specialization in Canadian junior high school children and the association with physical performance outcomes and/or injury in this group. Thus the purpose of this study was to describe sport specialization in Canadian youth and investigate associations with previous injury and physical performance. The specific study objectives were to investigate (1) levels of sport specialization and its association with school grade, school size and sex; (2) if sport specialization is associated with injury history; and (3) if sport specialization is associated with physical performance outcomes (vertical jump height, predicted maximal aerobic capacity (VO₂max), single-leg balance time, and Y-Balance performance).

METHODS

Participants

Participants included junior high school students (ages 11-16) from four schools in a Canadian city. Data for this cross-sectional study were collected as a component of a large randomized controlled trial (RCT) that evaluated the effectiveness of a physical education (PE) class neuromuscular training warm-up in reducing injuries. Schools that met the inclusion criteria (those that included a minimum of two PE classes within each of grades 7, 8, and 9 that were taught or co-taught by a PE specialist) were recruited in a randomized sequence to participate in the RCT, separated by East and West halves of the city. This was done to ensure there was a representative sample of schools across the city.

PROCEDURES

Prior to the beginning of the RCT, participants were asked to complete a baseline questionnaire at home with the help of their parents. Questions included information on demographics, injury history and physical activity participation, including hours of organized sport and recreational activity in the previous year. Previous injury was defined as any injuries sustained during a sport or recreational activity within the previous 12-months that required medical attention or resulted in time loss. Sport and recreational activity participation over the previous 12-months included the number of weeks and hours per week of participation. The questionnaire has been used in multiple community sports previously as part of a youth-based injury surveillance system and was found to be valid in a junior high school PE context.

The research coordinator spoke to each participant in person during the study period to ask them three questions regarding sport specialization. These three questions were
taken from Jayanthi and addressed year-round training, exclusion of other sports, and single-sport training, respectively: "Do you train for a sport more than eight months of the year?", "Have you quit other sports to focus on a main sport", and "Do you have a primary sport that you consider to be more important than other sports?". A "Yes" answer was scored as 1, and a "No" answer was scored as 0. Based on their answers, participants' specialization levels were categorized on a three-point scale, where a score of 0-1 indicated low specialization, a score of 2 indicated moderate specialization, and a score 3 indicated high specialization. If applicable, the Research Coordinator also recorded the sport that the participants considered to be their primary sport, as well as any other sport(s) that they played.

Physical performance measures included vertical jump height, aerobic capacity (predicted VO2max), single-leg eyes-closed dynamic balance time on an Airex foam pad (Airex Balance Pad®, L-group, St. Louis, MO) and Y-Balance test reach distance using the Y Balance Test™ kit (FunctionalMovement.com, Danville, VA). Vertical jump height was calculated as the distance (in centimeters) between standing reach height and reach height at the peak of the jump, measured using a marked fingerprint on paper adhered to the gymnasium wall alongside a vertical measuring tape. VO2max was predicted from the Fitnessgram PACER 20-m shuttle run using the following equation:

\[ \text{VO2max} = 45.619 + (0.353 \times \text{PACER laps}) - (1.121 \times \text{age}) \]

Foam pad balance was timed (in seconds) from the time the participant closed their eyes and were balancing on one foot (centered on the pad) with hands on their hips until they lost their balance, for a minimum of two seconds. Loss of balance included removing hands from hips, free leg touching balancing leg or floor, and/or balancing leg losing contact with the foam pad, or opening the eyes. If the participant did not balance for at least two seconds, the trial was repeated. The Y-Balance normalized composite reach distance, expressed as a percentage of limb length, was calculated for each foot as the sum of all reach distances (in centimeters) divided by a factor of 3.5 limb length, multiplied by 100. The best of three trials was used for vertical jump height and foam pad balance measures. Foam pad balance and Y-Balance were assessed on each foot, but only the maximum score from both feet was included in the analysis for each test.

STATISTICAL ANALYSIS

All statistical analyses were completed using Stata/SE 14.1 for Mac (StataCorp, College Station, TX). Frequencies and proportion of each sport specialization category (low, moderate, high) is reported for sex (boys vs girls), school size (small; 1-2 classes per grade vs large; 5-5 classes per grade) and grade (7, 8 or 9). Frequencies and proportions were also reported for previous injury characteristics (body part and injury type) and for primary sport reported.

Ordinal multivariable logistic regression analysis was used to assess if sex, grade or school size was associated with specialization category, adjusting for clustering by school. Multivariable logistic regression analysis, adjusted for sex, total sport hours over one year and clustering by school, was used to assess if specialization category was associated with history of injury.

Separate multivariable linear regressions were performed for each of the four performance outcomes, adjusting for interaction by sex and clustering by school, to assess if specialization category was associated with physical performance.

Outcomes for objectives 1 and 2 are presented as odds ratios (95% confidence intervals [CI]), whereas beta coefficients (β) for objective 3 were used to compare mean differences in balance performance (i.e., dynamic balance, Y-Balance), vertical jump performance, and aerobic capacity for high compared to low and moderate compared to low specialized groups. Statistical significance was based on an alpha level of 0.05 for objectives 1 and 2 and an alpha level of 0.0125 for objective 5, which was calculated from a Bonferroni correction to account for the four tests (alpha/number of tests=0.05/4).

RESULTS

Two hundred and thirty-eight students participated in the study (mean age 12.6 years, range 11-16 years, boys=49%). Students were rated in each specialization category including low (48%), moderate (34%) or high specialization (18%) (Table 1). Two of the four participating schools were larger schools, with three to five PE classes in each of the junior high grades (n=512 and n=525), while two were smaller schools with only two classes per grade (n=188 and n=165).

Forty-six (19%) students reported a history of previous musculoskeletal injury, with 50 injuries reported in total (Table 2). Most injuries were to the lower extremity (76%), particularly to the ankle (34%) and knee (18%). The most common injury types were sprains (52%), fractures (9%) and strains (10%). The most commonly reported primary sport was soccer (25%), followed by basketball (14%), hockey (11%) and dance (10%).

There was no significant association found between sex, grade or school size and specialization category (Table 3).

Ordinal multivariable logistic regression revealed that there was no independent association between history of injury and specialization category (Table 4). The odds of girls reporting an injury were higher than the odds of boys (OR=2.70, 95% CI 1.69 to 4.35; p<0.01), the other variables held constant, and the odds of injury increased (OR=1.001, 95% CI 1.0005 to 1.002; p=0.001) for every one-hour increase in yearly sport participation, the other variables held constant. This is equivalent to approximately 10% increase in the odds of injury for a consistent 2 extra hours per week during a year (i.e., increase by 104 hours per year).

Multivariable linear regression analyses (adjusting for total sport hours over previous year, interaction of sports specialization with sex and clustering by school) demonstrated no significant mean differences for vertical jump height, predicted VO2max, eyes closed dynamic or Y-Balance performance outcomes between high or moderate specialization categories compared to low specialization in girls or boys (Table 5).
Table 1. Proportions in each specialization category

<table>
<thead>
<tr>
<th></th>
<th>Low Specialization (n=113, 48%)</th>
<th>Moderate Specialization (n=82, 34%)</th>
<th>High Specialization (n=43, 18%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sex</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>58 (48%)</td>
<td>41 (34%)</td>
<td>23 (19%)</td>
</tr>
<tr>
<td>Boys</td>
<td>55 (47%)</td>
<td>41 (35%)</td>
<td>20 (17%)</td>
</tr>
<tr>
<td><strong>School size</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>48 (43%)</td>
<td>37 (33%)</td>
<td>27 (24%)</td>
</tr>
<tr>
<td>Large</td>
<td>65 (52%)</td>
<td>45 (36%)</td>
<td>16 (13%)</td>
</tr>
<tr>
<td><strong>School grade</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>52 (50%)</td>
<td>35 (34%)</td>
<td>17 (16%)</td>
</tr>
<tr>
<td>8</td>
<td>40 (50%)</td>
<td>24 (30%)</td>
<td>16 (20%)</td>
</tr>
<tr>
<td>9</td>
<td>21 (39%)</td>
<td>23 (43%)</td>
<td>10 (19%)</td>
</tr>
</tbody>
</table>

Values are reported as n(%).

Table 2. Injury and Primary Sport Characteristics

<table>
<thead>
<tr>
<th>Body part</th>
<th>n (%)</th>
<th>Injury type</th>
<th>n (%)</th>
<th>Primary sport</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle</td>
<td>17 (34%)</td>
<td>Sprain</td>
<td>25 (50%)</td>
<td>Soccer</td>
<td>35 (25%)</td>
</tr>
<tr>
<td>Knee</td>
<td>9 (18%)</td>
<td>Fracture</td>
<td>9 (18%)</td>
<td>Basketball</td>
<td>19 (14%)</td>
</tr>
<tr>
<td>Foot</td>
<td>7 (14%)</td>
<td>Strain</td>
<td>5 (10%)</td>
<td>Hockey</td>
<td>16 (11%)</td>
</tr>
<tr>
<td>Finger</td>
<td>3 (6%)</td>
<td>Dislocation</td>
<td>3 (6%)</td>
<td>Dance</td>
<td>14 (10%)</td>
</tr>
<tr>
<td>Leg</td>
<td>3 (6%)</td>
<td>Tendonitis</td>
<td>3 (6%)</td>
<td>Swimming</td>
<td>9 (6%)</td>
</tr>
<tr>
<td>Back</td>
<td>2 (4%)</td>
<td>Contusion</td>
<td>2 (4%)</td>
<td>Baseball</td>
<td>6 (4%)</td>
</tr>
<tr>
<td>Wrist</td>
<td>2 (4%)</td>
<td>Missing</td>
<td>2 (4%)</td>
<td>Badminton</td>
<td>5 (4%)</td>
</tr>
<tr>
<td>Arm</td>
<td>1 (2%)</td>
<td>Other</td>
<td>1 (2%)</td>
<td>Figure Skating</td>
<td>4 (3%)</td>
</tr>
<tr>
<td>Elbow</td>
<td>1 (2%)</td>
<td></td>
<td></td>
<td>Football</td>
<td>4 (3%)</td>
</tr>
<tr>
<td>Groin</td>
<td>1 (2%)</td>
<td></td>
<td></td>
<td>Gymnastics</td>
<td>3 (2%)</td>
</tr>
<tr>
<td>Shoulder</td>
<td>1 (2%)</td>
<td></td>
<td></td>
<td>Horseback riding</td>
<td>3 (2%)</td>
</tr>
<tr>
<td>Trunk</td>
<td>1 (2%)</td>
<td></td>
<td></td>
<td>Lacrosse</td>
<td>3 (2%)</td>
</tr>
<tr>
<td>Toe</td>
<td>1 (2%)</td>
<td></td>
<td></td>
<td>Mixed Martial Arts</td>
<td>3 (2%)</td>
</tr>
<tr>
<td>Missing</td>
<td>1 (2%)</td>
<td></td>
<td></td>
<td>Taekwondo</td>
<td>3 (2%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cheerleading</td>
<td>2 (1%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ringette</td>
<td>2 (1%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Skateboarding</td>
<td>2 (1%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Karate</td>
<td>2 (1%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Martial Arts</td>
<td>2 (1%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Parkour</td>
<td>2 (1%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rock climbing</td>
<td>2 (1%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sprinting</td>
<td>2 (1%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tennis</td>
<td>2 (1%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Volleyball</td>
<td>2 (1%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Missing</td>
<td>7</td>
</tr>
</tbody>
</table>

DISCUSSION

The main aims of this study were to describe sport specialization in Canadian junior high school students and investigate levels of sport specialization and links to injury and physical performance in this population. This is one of the
Table 3. Ordinal multivariable logistic regression demonstrating odds of being in a more highly specialized sport category by sex, school size, and grade

<table>
<thead>
<tr>
<th></th>
<th>Cumulative ORs (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sex</strong></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>Reference</td>
</tr>
<tr>
<td>Boys</td>
<td>0.9 (0.6 to 1.4)</td>
</tr>
<tr>
<td><strong>School size</strong></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>Reference</td>
</tr>
<tr>
<td>Large</td>
<td>0.6 (0.4 to 1.1)</td>
</tr>
<tr>
<td><strong>School grade</strong></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Reference</td>
</tr>
<tr>
<td>8</td>
<td>1.1 (0.4 to 2.6)</td>
</tr>
<tr>
<td>9</td>
<td>1.4 (0.6 to 3.4)</td>
</tr>
</tbody>
</table>

OR=odds ratio comparing high to moderate and low specialization, and moderate to low specialization, given the other variables held constant; CI=confidence interval

Table 4. Multivariable logistic regression showing odds ratios of reporting a history of injury

<table>
<thead>
<tr>
<th>Specialization category</th>
<th>Adjusted Odds Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Reference</td>
</tr>
<tr>
<td>Moderate</td>
<td>1.94 (0.86 to 4.35)</td>
</tr>
<tr>
<td>High</td>
<td>2.21 (0.43 to 11.37)</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>Reference</td>
</tr>
<tr>
<td>Girls</td>
<td>2.70 (1.69 to 4.35)*</td>
</tr>
<tr>
<td><strong>Total sport Hours</strong></td>
<td></td>
</tr>
<tr>
<td>Per hour increase (per year)</td>
<td>1.0010 (1.0005 to 1.0020)*</td>
</tr>
</tbody>
</table>

Multivariable logistic regression with variables sports specialization, sex, total sport hours over one year, and clustering by school; *p≤0.05, CI=confidence interval

few studies in this field to focus on the younger adolescent age group (ages 11-16), adjust for sport participation hours, and include measures of physical performance. The proportion of highly specialized students was approximately 10% lower than reported in several previous studies,1,10,19,20, perhaps reflecting the younger average age in this group. The proportion of highly specialized children has recently been reported to be lower in a group of 10-13 year old children.11 Junior high school students may not face the same pressure from their school, parents or coaches to specialize. Authors of two previous studies have reported lower levels of highly specialized high school students similar to that seen in the current study.9,21 Comparable to previous studies, level of specialization was not associated with sex or school grade.19 This does however contrast a recent study by Biese et al.22 that reported more highly specialized female athletes compared to male athletes in a group of 12-18 year old adolescents and this is an area that requires further investigation. A higher proportion of highly specialized high school students have been reported in larger schools19 but this was not the case in the current junior high school group. This may be due to differences in the definition of small versus large school used. These findings suggest sport specialization is not as common in junior high school students but the pattern across sex and grade is similar to high school.

Being highly or moderately specialized did not increase the odds of reporting a history of injury. This confirms the findings of recent studies which have failed to show an independent link between sport specialization and injury.11,23 This is however in contrast to several studies that have reported increased injuries in highly specialized groups.10,19,20 While direct comparisons should be made with caution due to differences in methods of rating specialization, injury definitions and adjustments for confounding variables (sports hours are often not accounted for and the injury definition in the current study looks at injuries sustained over the previous year), this may again be due to the relatively younger group investigated in the current study. The proposed increased risk of injury caused by repetitive movements in a single sport may only occur following a certain period of exposure and younger students may not have reached this threshold. Additionally, early specialized children may receive better technique, move-
ment skill and strength and conditioning coaching which could offer protection from injury. In the development of the adolescent athlete, strength and skill competence are considered key components for both performance and injury prevention.\textsuperscript{24}

Consistently, the young average age of the group one might expect a greater impact of high specialization and greater injury risk due to the added effect of the growth spurt. While there is substantive variation in the chronological age at which adolescents experience peak growth rates it is generally thought to occur between the ages of 11 and 13.5 years.\textsuperscript{25} A further complication during this period of rapid growth is the increased incidence of growth-related conditions such as Osgood-Schlatter syndrome which may be overuse related but equally could be of insidious onset. Interestingly, injuries reported in the current study were mainly acute in nature and this may also explain the lack of association with specialization level which has often been linked to overuse injuries previously.\textsuperscript{10} Nonetheless, the increased intensity of training and competition associated with early specialization potentially also increases the risk for acute injuries and this has been reported recently in a group of adolescents competing in a variety of organized sports.\textsuperscript{22} Consistent with previous studies, this study found girls and those students with higher total hours of exposure to sports had larger odds of reporting a history of injury.\textsuperscript{10,20,26,27} It has been reported that the association between sport specialization and injury in adolescents may differ by sex and by sport.\textsuperscript{23} Specifically, high specialization was linked to injury in females but not males, potentially due to the differing impact of specialization on neuromuscular control. Additionally, the relationship is likely to be sports specific with recent evidence supporting a link between specialization and injury in volleyball but not in basketball or soccer.\textsuperscript{28}

No differences were found in physical performance between high or moderately specialized students and low specialized students. Again, it is difficult to make direct com-

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Table 5. Multivariable linear regression showing mean performance outcomes by specialization group, and mean differences compared to low specialized group as reference.

<table>
<thead>
<tr>
<th></th>
<th>Low Specialization</th>
<th>Moderate Specialization</th>
<th>High Specialization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical jump height (cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>Mean (98.75% CI)</td>
<td>31.0 (23.6 to 38.3)</td>
<td>30.5 (22.5 to 38.6)</td>
</tr>
<tr>
<td></td>
<td>Mean difference</td>
<td>-0.4 (-9.8 to 8.9)</td>
<td>1.0 (-1.4 to 3.3)</td>
</tr>
<tr>
<td>Boys</td>
<td>Mean (98.75% CI)</td>
<td>35.9 (27.6 to 49.4)</td>
<td>38.0 (26.6 to 49.4)</td>
</tr>
<tr>
<td></td>
<td>Mean difference</td>
<td>2.1 (-9.7 to 13.8)</td>
<td>-0.3 (-12.7 to 12.0)</td>
</tr>
<tr>
<td>Predicted VO$_2$max (mL/kg/min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>Mean (98.75% CI)</td>
<td>41.7 (36.9 to 46.4)</td>
<td>44.7 (42.5 to 47.0)</td>
</tr>
<tr>
<td></td>
<td>Mean difference</td>
<td>3.1 (-3.5 to 9.7)</td>
<td>2.6 (-6.3 to 11.4)</td>
</tr>
<tr>
<td>Boys</td>
<td>Mean (98.75% CI)</td>
<td>45.3 (41.9 to 48.8)</td>
<td>48.2 (45.0 to 51.5)</td>
</tr>
<tr>
<td></td>
<td>Mean difference</td>
<td>2.9 (-3.0 to 8.8)</td>
<td>2.2 (-6.4 to 10.8)</td>
</tr>
<tr>
<td>Foam pad unipedal eyes-closed dynamic balance time (sec)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>Mean (98.75% CI)</td>
<td>6.8 (1.7 to 11.8)</td>
<td>7.5 (4.1 to 10.9)</td>
</tr>
<tr>
<td></td>
<td>Mean difference</td>
<td>0.8 (-1.4 to 2.9)</td>
<td>0.8 (2.9 to 4.5)</td>
</tr>
<tr>
<td>Boys</td>
<td>Mean (98.75% CI)</td>
<td>6.0 (2.9 to 9.1)</td>
<td>7.9 (4.3 to 11.6)</td>
</tr>
<tr>
<td></td>
<td>Mean difference</td>
<td>1.9 (-4.3 to 8.2)</td>
<td>0.5 (-1.0 to 2.0)</td>
</tr>
<tr>
<td>Y-balance normalized composite reach distance (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>Mean (98.75% CI)</td>
<td>84.2 (68.9 to 99.4)</td>
<td>85.4 (71.1 to 99.7)</td>
</tr>
<tr>
<td></td>
<td>Mean difference</td>
<td>1.2 (-6.5 to 9.0)</td>
<td>2.6 (-13.4 to 18.7)</td>
</tr>
<tr>
<td>Boys</td>
<td>Mean (98.75% CI)</td>
<td>84.0 (78.8 to 89.1)</td>
<td>91.0 (74.9 to 107.1)</td>
</tr>
<tr>
<td></td>
<td>Mean difference</td>
<td>7.0 (-10.1 to 24.1)</td>
<td>0.6 (-5.8 to 7.0)</td>
</tr>
</tbody>
</table>

Multivariable linear regression adjusting for total sport participation hours over the previous year, interaction by sex and clustering by school; CI=confidence interval.
Comparisons to previous studies due to differences in analysis, ratings of specialization and physical tests. However, the lack of association found between specialization category and composite reach distance on the Y-Balance test has been reported previously in high school athletes. Additionally, in a group of young gymnasts no association was found between level of fitness or functional performance and level of specialization. Findings from the current study contrast the positive link between early sport sampling (low specialization) and cardiovascular fitness reported previously in a group of young boys. It is thought that high specialization may negatively impact neuromuscular development due to reduced exposure to variety in movement patterns resulting in a reduction in physical abilities such as balance performance. Again, an alternate theory is that specialization could be beneficial as it may give students earlier exposure to more informed coaches (better facilitators of technique and skill) and superior training programs that better develop physical condition, including balance. Additionally, well designed programs (that may include some highly specialized students) often include exposure to a variety of movement experiences. This, combined with increased volumes of sport participation that provide an enhanced training stimulus (but are still appropriate for the phase of maturation), may improve physical capability and in fact protect specialized students against injury and reduce risk.

This study has several limitations that need to be acknowledged. The sample size is relatively small and thus the proportion of highly specialized students is likely not generalizable to the entire population of junior high school students. Additionally, there were many different sports included and thus the rates of specialization and association with injury may not be representative of the situation in individual sports. It is likely that variations in the structure and rules of various sports may influence specialization and injury rates. Previous studies have reported different specialization patterns across different sports. Furthermore, the method for rating specialization based on self-report, while used in several previous studies, is limited with authors recently highlighting the need for further validation studies in sports specific contexts. A strength of this study was that each participant was spoken to individually to confirm the rating of specialization. This allowed clarification of any misinterpretations regarding the questions. For example, differentiating between training for a sport versus playing a sport for leisure when addressing year-round training. In other cases, some participants mentioned that they had only ever participated in one sport, and therefore had never quit other sports. This may have underestimated their total specialization score and contributed to the lower proportion of highly specialized students. This limitation of the rating system has recently been acknowledged by others and an additional question added. Finally, as is always the case with retrospective injury data there is the potential for recall bias.

CONCLUSION

There is evidence of sport specialization in Canadian junior high school students, but levels are lower than many previous reports. Increased specialization did not increase the odds of reporting a history of musculoskeletal injury nor was it associated with a range of physical performance measures. Participating in more total sports hours increased the odds of reporting a history of injury and girls had higher odds of reporting a history of injury compared to boys.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest in submitting this article.

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Effective Attentional Focus Strategies after Anterior Cruciate Ligament Reconstruction: A Commentary

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Keywords: rehabilitation, motor learning, acl, attentional focus

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Individuals after anterior cruciate ligament reconstruction (ACLR) have a high rate of reinjury upon return to competitive sports. Deficits in motor control may influence reinjury risk and can be addressed during rehabilitation with motor learning strategies. When instructing patients in performing motor tasks after ACLR, an external focus of attention directed to the intended movement effect has been shown to be more effective in reducing reinjury risk than an internal focus of attention on body movements. While this concept is mostly agreed upon, recent literature has made it clear that the interpretation and implementation of an external focus of attention within ACLR rehabilitation needs to be better described. The purpose of this commentary is to provide a clinical framework for the application of attentional focus strategies and guide clinicians towards effectively utilizing an external focus of attention in rehabilitation after ACLR.

Level of Evidence
5

INTRODUCTION

A rupture of the anterior cruciate ligament (ACL) is one of the most common sport related injuries. Patients who want to continue to pursue pivoting type of sports often undergo ACL reconstruction (ACLR) followed by extensive periods of rehabilitation. However, patients after ACLR still may have up to a 40 times greater risk of reinjury relative to those without injury.1 Following ACLR, aberrant movement patterns have been linked to an increased risk of a second ACL injury and may also explain why not all patients return to their pre-injury level.2–4 Current rehabilitation approaches may not optimally target deficits in motor control. An emphasis on the dynamics of skill (re)acquisition in current rehabilitation programs have been recommended to target these motor control deficits.5–9 To best improve motor learning and performance after ACLR clinicians may need to consider the way in which verbal instruction and feedback influences attentional focus and thus skill development throughout the rehabilitation process.9–11

A traumatic injury, such as an ACL rupture, may trigger a cognitive disruption and has the potential for maladaptive neuroplasticity with motor and premotor areas of the cortex being more active during simple movement tasks compared to uninjured individuals.12,13 Loss of function, pain, fear of reinjury, and other psychological factors may cause a shift in focus towards the injured area such as the knee. Therefore, the patient recovering from the injury is excessively focusing on the injured area during movement execution.14–17 This focus directed towards body movements, and accompanying brain adaptations, potentially deters motor performance after sports injury. Return to high level performance may benefit from the adoption of an external focus of attention when providing instructions directed to-
wards the intended movement effect.\textsuperscript{17,18} However, clinicians utilize internal focus instructions over 90% of the time.\textsuperscript{19,20} This extra focus on the body may stimulate the motor and premotor areas of the cortex to be active to a greater degree. While a rationale may be that an internal focus is necessary to progress from the cognitive stage of learning to the associative and automatic stage, this view is not well supported in the motor learning literature.\textsuperscript{21,22} Furthermore, misconceptions regarding when to use an external focus of attention (e.g. early vs. late rehabilitation or description vs. execution of movement) alongside a recent body of literature that has attempted to extend this work into hybrid models, warrants a critical evaluation. Therefore, the purpose of this commentary is to provide a clinical framework for the application of attentional focus strategies and guide clinicians towards effectively utilizing an external focus of attention throughout ACLR rehabilitation.

CONSIDERING AN EXTERNAL FOCUS OF ATTENTION TO OPTIMIZE MOVEMENT OUTCOME

A subtle change in the wording of exercise instruction prior to movement execution can promote an external focus of attention so that attention is directed to one's intended effect of the movement (goal-directed attention), in contrast to paying attention to one's own body movements (i.e., internal focus of attention or self-directed attention). This external focus of attention centers on the ability to engage both the perceptual-cognitive and physical performance factors in the functional task environment.\textsuperscript{23} For example, in an effort to improve balance performance, a patient may perform a single leg balance task on a Bosu ball (BOSU, Ashland, OH). A clinician may instruct the patient using an internal focus of attention such as, "minimize movement of the feet". However, by just changing one word to "minimize movement of the Bosu" the instructions become externally focused. In addition, an external focus of attention can also be elicited by means of a metaphor (e.g., "stand still like you are stuck on Velcro"), analogy ("imagine yourself as hard as possible off the ground after landing on the force plate"), or an imagined object, where a mental image of the movement goal is obtained (e.g., thinking of the leg as a line, "keep the line straight").\textsuperscript{24–28}

The benefit of an external focus of attention compared to an internal focus of attention for enhancing motor skill learning and performance has consistently been shown through a large body of evidence across different populations, tasks, and skill levels.\textsuperscript{10,29,30} These include tasks such as balancing, running, agility performance, change of direction performance, force production, and horizontal and vertical jump performance.\textsuperscript{6,31–38} Collectively, an external focus of attention has been shown to produce more accurate performance, improved reaction time, and more efficient movement (e.g., reduced muscular activity).\textsuperscript{39–41} Also in athletes following an ankle sprain, those who received external focus instructions to "keep your balance by stabilizing the platform" demonstrated improved balance after training compared to an internal focus group instructed to "keep your balance by stabilizing your body".\textsuperscript{18}

In primary ACL injury prevention, there is evidence which illustrates how an external focus of attention can lead to improved movement form, jump performance, and result in safer landing mechanics. A literature review on jump and landing technique showed that an external focus of attention improves movement with greater knee flexion angles, greater center of mass (CoM) displacement, lower peak vertical ground reaction force (vGRF), and improved neuromuscular coordination, while maintaining or improving performance (i.e., jump height or distance).\textsuperscript{6} These findings suggest a decrease in ACL injury risk.

In another example, the effects of an internal and external focus of attention on landing forces were compared in adolescent rugby players before and after a two-week training program. An external focus directed to "focus on landing softly" resulted in a reduction in landing forces with the addition of a secondary cognitive task compared to an internal focus of attention directed to "focus on bending your knees when you land," which showed an increase in landing forces with the addition of a secondary cognitive task.\textsuperscript{42} Therefore, an external focus of attention utilized less conscious control in dual-task conditions which is similar to the conditions that athletes may face when returning to sport. Similarly, using an external focus of attention was also shown to immediately result in reduced landing stiffness in female athletes as well as improved landing technique compared to an internal focus of attention.\textsuperscript{43,44} In a recent study utilizing the Landing Error Scoring System (LESS), colored tape was attached to each participant's mid patella alongside the tips of their shoes.\textsuperscript{45} The external focus of attention instructions were: "when landing from the box, focus on pushing the red tapes (attached to the mid patella) forward, and pointing the green tapes (attached to the tips of the shoes) forward." The internal focus instructions were, "when landing from the box, focus on pushing your knees forward, and pointing your toes forward." Better landing quality, expressed by a lower LESS score, was achieved using an external focus of attention compared to internal focus of attention. In another jump landing study, athletes training with an external focus of attention ("push yourself as hard as possible off the ground after landing on the force plate") demonstrated greater knee flexion range of motion compared to another group training with an internal focus of attention ("extend your knees as rapidly as possible after the landing on the force plate"). These results were not only retained one week later, but also carried over to an unanticipated sidestep cutting task.\textsuperscript{46}

An external focus of attention may be successful by facilitating functional connectivity, modulating surround inhibition, and increasing intracortical inhibition to resemble the sensorimotor integration typically seen in more skilled action.\textsuperscript{47–49} The constrained action hypothesis suggests that an internal focus disrupts the motor system by promoting conscious control which leads to a breakdown in the in the otherwise natural organized coordination of one's movement. On the other hand, an external focus allows for a greater degree of self-organization by promoting automatic control processes.\textsuperscript{50} Therefore, if movements are not planned in terms of the intended movement effect, but in terms of specific body movements, the outcome will be less-
Moreover, using an app-based active muscle training program (GenuSport Knee Trainer, Weber-Spickschen) where the aim is to produce force by pushing the knee down into the measuring unit, patients post ACLR improved strength significantly more compared to a control group who trained with an internal focus of attention. In the former, the patient attends to a game on the tablet, rather than their body part, to control a flight course of an airplane with the aim to destroy balloons.

The second assumption is that once one starts to transition into the late rehabilitation phase, adding aspects to the environment (e.g., hurdle, ball, or an unstable surface) leads to a shift to an external focus of attention. However, adding environmental factors do not shift the patient’s attention to an external focus but simply refer to objects in the environment and not one’s intended movement effect. Likewise, in the later stages of rehabilitation, it is suggested to progress from closed skills (e.g., usually self-paced, predictable skills that are decontextualized from the environment) with an internal focus of attention to more open, sport-specific skills with an external focus. Here, it is assumed that an internal focus of attention is better or equivalent for closed skills and external focus for open skills (e.g., patients have to make decisions and adapt their skills to an unpredictable environment). In contrast, it is also assumed that practicing closed skills cannot benefit from external focus instructions because the individual lacks correct movement patterns. However, the benefit of an external focus has been shown in both closed and open skills. This effect also extends across early and late stages of learning. Therefore, clinicians should evaluate the task goal, establish an optimal challenge level, consider patient preferences regarding the appropriate instructions, and create an external focus in relation to the patient’s action capability within the functional task environment. Regardless of utilizing a closed or open skill, it is recommended to keep exercises as representative as possible of conditions that patients will return to through all stages of rehabilitation.

**STAGES OF LEARNING**

Rehabilitation after ACLR can be categorized into three stages: early, intermediate and late. For the intermediate phase, it has been recommended that an internal focus of attention is necessary to achieve sound movement patterns to restore motor function (e.g., muscle contraction ability) with patients only being able to adopt the ‘right’ way of moving when you tell them explicitly how to do it. Then, during the progression of the exercises, external factors that increase task complexity such as hurdles or unstable surfaces should be added. These assumptions are based on more traditional views of motor learning where a linear progression for learning or re-learning motor skills is paramount. Traditional teaching of exercise also tends to emphasize specific step-by-step detailed instruction of a movement pattern for repetitive rehearsal (providing an “optimal” way to perform a specific movement), as well as the application of corrective and frequent feedback in repeating a movement technique. Briefly, through this lens, attentional demands transition from being under high conscious control to being controlled with very little cognitive effort over time as movements become more accurate, consistent, and efficient. However, as described by a more recent non-linear progression for learning, a given range of possible movement solutions should allow clinicians to guide patients as they self-organize and find their optimal movement to reach the goal of the movement (e.g., soft landing). As compared to internal focus of attention, an external focus provides the opportunity for self-organizing, as shown by efficient recruitment of motor units, fewer co-contraction of muscles, increased functional variability, and a “freeing” of the body’s degrees of freedom. An external focus seems to speed up the learning process, displaying adoption of movement patterns similar to more skilled performances.

**DESCRIPTION VS. EXECUTION**

Another misconception is that with an external focus of attention, patients are not allowed to know the goal of the exercises (e.g., increase knee flexion, deeper landing) or focus on their body to perform the requested movement. However, an external focus does not mean that the patient is not aware of her or his body movements but rather means the patient is focusing on the intended movement effect – while preparing for the execution of a ballistic skill (e.g., throwing or hitting a ball) or during the execution of a continuous skill (e.g., balancing, swimming, cross-country skiing). Adopting an external focus is thus related to the planning of the movement, not with the processing of intrinsic feedback or bodily awareness. This does not mean that a clinician must never use body related words that elicit an internal focus of attention but verbiage should be limited to the patient’s action capability within the functional task environment. Regardless of utilizing a closed or open skill, it is recommended to keep exercises as representative as possible of conditions that patients will return to through all stages of rehabilitation.
Figure 1. Illustrating the difference between explaining the goal of an exercise and the subsequent attentional foci a clinician can choose for his/her instruction/feedback just prior to practice.

the patient the general goal of an exercise. For example, "the goal of this exercise is to improve your knee bending while landing, as this promotes a softer landing, which is better for your knee." Then, as your patient is preparing to execute the exercise, it is critical to shift their attentional focus that corresponds closest to the task goal. This means, the physiotherapist can choose either an internal focus of attention (e.g. "flex your knee when landing", as most frequently done) or an external focus of attention (e.g. "focus on landing with as little noise as possible" or "pretend you are going to sit on a chair when landing") (Figure 1). With the external focus of attention, you do not have to explicitly tell the patient how, rather give the patient the freedom to come up with a solution to complete the goal of the task in the functional environment (less noise during landing from a jump). Here the patient is allowed to seek out relevant features of the task environment to shape self-organization. One must recognize there will not be one perfect movement solution. Based upon the intrinsic dynamics of the patient and the channeling of exploratory movement solutions, clinicians should highlight the existence of a multitude of stable movement patterns and solutions for a task. In the example above, the end effect is the same (i.e., increased bending in the knee when landing), however the focus of the patient when executing the motor task is different. As a result, shifting to an external focus may lead to better movement form both in practice, during retention, and upon transfer to more competition and game-like interactions.

THE RIGHT FOCUS

While the purpose of this commentary is to illustrate that word choices are crucial to implement an external focus of attention, this is not a new phenomenon or discussion. Over the last several years there has been an increase in research related to attentional focus, ACLR rehabilitation, and biomechanical risk factors related to ACL injury. However, the terminology encompassing an external focus of attention has lately been extended to descriptions such as: 'external factors', 'external cueing', 'external focus of control', 'external goal', 'externally focused motivation', 'external feedback', 'external feedback motivation', 'visual external focus' and 'external visuospatial environment'. As a result, the research relating to attentional focus can be hard to interpret. Attentional focus is defined as the conscious effort of a patient to focus their attention on explicit thoughts or feelings in an effort to execute a task with superior performance. Attentional focus relates closely to what you tell your patient(s) prior to the execution of the exercise whereby you direct them where to focus their attention: internally (i.e. on body part(s) and movement(s)) or externally (i.e. on intended movement effect). Hybrid instructions, such as "step toward the cone by pushing the floor away with your back foot" for the execution of a lunge or "balance a board flat across your shoulders" for the correction of excessive lateral trunk flexion on squat jump landing are not recommended. These hybrid instructions are not purely an external focus of attention as they include a reference to a body part: the back foot. This "self-invoking trigger" may result in inefficient activation of the neuromuscular system. A minor change such as "step toward the cone by pushing the floor away with your back shoe" or "balance a board flat across your shirt" would make this instruction solely an external focus instruction. While the inclusion of motor learning principles in physical therapy...
Table 1. Example exercises and attentional focus strategies for early phase rehabilitation.

<table>
<thead>
<tr>
<th>EXERCISE EXAMPLES</th>
<th>INTERNAL FOCUS</th>
<th>EXTERNAL FOCUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee Extension on a Bolster</td>
<td>“Press your knee toward the table”</td>
<td>“Press the bolster toward the ground”</td>
</tr>
<tr>
<td>Straight Leg Raise</td>
<td>“Lift your leg 6 inches off the ground”</td>
<td>“Lift your shoe 6 inches off the ground”</td>
</tr>
<tr>
<td>Glute Bridge</td>
<td>“First, tighten your abdominals, keep them activated, then lift your hips off the floor”</td>
<td>“Push into the ground and bring this marker off the floor” (marker on waist)</td>
</tr>
<tr>
<td>Balance (Single-leg on balance board)</td>
<td>“Focus on keeping your pelvis as still as possible”</td>
<td>“Minimize the movement of the balance board”</td>
</tr>
<tr>
<td>Gait</td>
<td>“Extend your knee while walking”</td>
<td>“Focus on the markers drawn on the floor” (markers based on symmetrical gait cycle)</td>
</tr>
</tbody>
</table>

Using a criteria-based, evidence-based constructed approach to rehabilitation after ACL surgery is essential to progress a patient systematically and successfully through the rehabilitation process. It is imperative to control post-operative pain, inflammation and swelling during the first weeks of rehabilitation. Calming the knee down initially, starting slowly, will allow the rehabilitation to accelerate faster in the long run. Post-operative rehabilitation begins with a range of movement exercises, emphasizing full passive knee extension and weight-bearing activities immediately post-operatively.

Claudia and implementing an external focus takes time and requires practice but may help to optimize patient care. Clinical examples that will offer clinicians examples of how to incorporate external focus in their practice are provided for the early (Table 1), intermediate (Table 2), and late (Table 3) phases of rehabilitation.

CONCLUSION

Targeting deficits in motor control is a critical component for ACLR rehabilitation. One way to potentially improve neuromuscular control is by altering how attentional focus is directed when performing motor skills across early, middle, and late phases of rehabilitation. An external focus of attention offers an alternative strategy that facilitates automatic movement control and results in more effective performance and learning than an internal focus of attention. Clinicians are encouraged to adopt an external focus of attention in their practice over an internal focus of attention to promote optimal movement strategies throughout rehabilitation interventions. Further, researchers should strive to use similar terminology when it comes to describing attentional focus interventions into experimental designs.

DISCLOSURE STATEMENT

No financial interest or benefit has arisen from the direct applications of this research. The authors report no conflicts of interest.

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Table 2. Example exercises and attentional focus strategies for intermediate phase rehabilitation.

| INTERMEDIATE | EXERCISE EXAMPLES | | | | |
|---|---|---|---|---|
| As the patient becomes stronger and elicits more stable motor patterns, exercises are varied more often and become sport specific. Both pain and amount of exertion should continue to be monitored. | **INTERNAL FOCUS** | **EXTERNAL FOCUS** | | |
| Running | Bilateral squat on unstable surface | Split squat jump | Bilateral rotational jump 90° turn | Single leg hopping multiple directions | |
| “Land on your forefoot” | “Lower your hips until your thighs are parallel to the floor, then return to standing” | “Flex your knees to 90° when landing” | “Start in a squat position, jump and turn so that your hips are facing the wall while flexing the knees when landing” | “Flex your knees to 90° when landing” | |
| | “Extend your knees away from the ground” | | | | |
| | “Keep your knee over your toes when landing” | | | | |
| “Touch floor with coloured part of your shoes” (tape on forefoot) | “Imagine you are going to sit on a chair and then return to standing” | “Push the floor away when jumping” | “Start in a squat position, jump and turn so that the marker is facing the wall” (tape marker (or shirt logo) on chest) | “Point the tape towards the cones when landing” (tape on tibial tuberosity) | |
| “Lower noise from both feet from 8 to 4” (using VAS scale 0 is no noise, 10 is loud noise) | “Lower down until you slightly tap the bench” (bench behind person) | “Get away from the grass/floor when jumping” | “Start in a squat position, jump and keep tension on the cord and land” (elastic cord around waist) | “Keep the pieces of tape in line of each other when landing” (tape on tibial tuberosity and on dorsal side of foot) | |
| | “Keep the water as still as possible” (cup of water on the unstable surface) | “Drive the tape to the sky” (tape on chest) | “Lower noise when landing from 8 to 4” (using VAS scale 0 is no noise, 10 is loud noise) | | |
| | “Lower in line with your laces” | “Drive the tape down and back” (tape on hips) | | | |

*International Journal of Sports Physical Therapy*
Table 3. Example exercises and attentional focus strategies for late phase rehabilitation.

<table>
<thead>
<tr>
<th>LATE</th>
<th>EXERCISE EXAMPLES</th>
<th>INTERNAL FOCUS</th>
<th>EXTERNAL FOCUS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Agility 'L' Run</td>
<td>&quot;For the turn, focus on planting your foot as quickly as possible&quot;</td>
<td>&quot;For the turn, focus on getting to the next cone fast&quot;</td>
</tr>
<tr>
<td></td>
<td>Lateral Shuffle</td>
<td>&quot;Bend your knees to 90° when shuffling&quot;</td>
<td>&quot;While shuffling, keep the bottom of your shorts parallel to the floor&quot;</td>
</tr>
<tr>
<td></td>
<td>Cone Drill</td>
<td>&quot;When making the cut, bend your knee&quot;</td>
<td>&quot;When making the cut, push yourself off of the ground as hard as possible&quot;</td>
</tr>
<tr>
<td></td>
<td>Unanticipated Change of Direction</td>
<td>&quot;When making the cut, keep your knees over your toes&quot;</td>
<td>&quot;When making the cut, move towards the new cone quickly&quot;</td>
</tr>
</tbody>
</table>

"When making the turn, move the logo on your shirt towards your running direction"  
"When making the turn, point the tip of your shoe towards new running direction"  
"When making the cut, point the tape on the tip of your shoe towards new running direction"
REFERENCES


Clinical Suggestion/Unique Practice Technique

Telehealth Physical Therapy: More Than an Alternative to In Person Care of the Young Athlete

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Keywords: young athlete, telehealth, physical therapy, rehabilitation, pediatric, adolescent

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The shift to telehealth due to COVID-19 revealed that a new care model for the young athlete, which combines in-person and virtual visits, could be an enhancement to in-person care alone. This clinical suggestion is novel as it discusses the utility of a hybrid care model for the young athlete, which has not yet been described. Interacting with the patient and family virtually in the home environment offers benefits that are difficult to achieve in the clinic. Opportunities such as the ability to custom tailor the home program with consideration of the patient’s learning abilities, provide movement quality feedback outside of the clinical environment, observe parent/caregiver feedback, involve family members who may not be available to attend in-person visits, and the possibility of converting an in-person cancelation to a telehealth visit in order to maintain continuity of care, are examples of how this model may optimize treatment. Consideration of investigating the impact on clinical outcomes and cost effectiveness is recommended.

Level of Evidence
5

THE PROBLEM

Integration of a home exercise program is a vital component to a successful outcome when treating the young athlete, however, ensuring accurate performance is difficult. Without the ability to observe the patient in the home environment and provide real-time instruction to him/her and parents/caregivers it is challenging to determine if the program is being properly implemented. Home exercise program technique out of the clinical setting may fall short without the watchful eye of a clinician. Parents/caregivers independently attempting to provide proper guidance and feedback regarding the program in the home environment may not be effective. When in the clinic, the PT asking the patient to demonstrate their program, with and without parent/caregiver feedback, may not be sufficient to achieve the same results when back at home.

THE SOLUTION

Shelter in place due to COVID-19 prompted a rapid shift in the profession of physical therapy from in-person visits to telehealth.1,2 In the young athlete population this presented an opportunity to provide care using a new practice model where the patient could be visualized and treated in the home environment virtually with his/her parents/caregivers. This shift has revealed that telehealth can be a powerful tool which allows observation of movement outside of the clinic, instruction of parents/caregivers regarding feedback on movement quality while at home, the development of a custom-tailored home program with consideration of the patient’s learning abilities and home setting, and alternative scheduling opportunities, all of which may enhance outcomes and reduce healthcare costs in this population. This process can assist in mitigating the problem of ineffective home program performance due to improper exercise technique, which can have a detrimental impact on recovery. This clinical suggestion is novel in that it discusses the

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utility of a hybrid care model specifically for the young athlete, which has not yet been described.\(^1,3,4\)

One advantage of telehealth as an adjunct to in-person care of the young athlete is the ability to observe patient movement patterns outside of the clinical environment. The clinic is an ideal setting for performance of exercises and functional movement, particularly with the therapist physically present providing hands on facilitation of proper technique. At home through a virtual visit the young athlete is more likely to demonstrate the movement patterns they would typically perform when not in the direct presence of the therapist. Additionally, telehealth provides the potential to assess the young athlete in his/her sport specific setting. This can be outdoors or indoors such as on a court surface or on the ice.

Another benefit of virtual visits for this population is education of the parent/caregiver regarding observation of movement and how to instruct the patient on proper exercise technique, as it is possible that learning in the clinic may not translate completely to accurate performance of these skills at home. Accurate performance of the young athlete’s treatment plan in the home environment is challenging to identify in the clinic, where therapists have the ideal equipment, space, and surfaces to perform tasks. Physical therapists may discover through telehealth that the implementation of the program at home is not as intended and this inconsistency with our instruction may not be recognized by the patient and parents/caregivers. With this discovery physical therapists are positioned to educate the patient and parents/caregivers more accurately about the plan and to improve program efficacy. Additionally, parents/caregivers who may not be able to attend clinic-based visits may be available through telehealth to obtain this same learning.

Developing an effective home program for the young athlete is very challenging as there are multiple factors to consider:

- Is the patient able to think abstractly and adapt the program to the home environment?
- Does the patient have any learning impairments? Though he or she may not be receiving special education, that does not necessarily mean that there are no barriers to learning.
- Does the patient truly understand the exercises and their intended purpose?
- What is the patient’s ability to provide effective feedback to the therapist or parents/caregivers regarding muscle fatigue versus pain?
- To what extent is the parent or caregiver able to provide guidance regarding the details of the exercises, such as the proper movement patterns, alignment, and pace?
- What will be the ideal choice and number of exercises to optimize program adherence?
- Are there appropriate locations in the home to perform the various exercises?
- Does the patient have access to any exercise equipment? If so, what items? If there is access to a school or fitness facility how likely is it that the patient will go due to time constraints or transportation logistics?

While these factors can be addressed to some extent in the clinic, telehealth provides the opportunity to optimize home program implementation. Being able to see the young athlete in the home environment provides the therapist with a wealth of information that is difficult for the family to convey during in-person care and challenging to obtain through discussion. The therapist’s ability to see such things as the amount of space for exercise, height of stairs, type of flooring, exercise equipment, household items available, exercise technique etc. enables him/her to accurately instruct the patient in home program performance. For example, an injured adolescent athlete who was instructed to advance single limb balance to an unstable surface at home to mimic a foam balance pad in the clinic, stood on a pillow. In observing the patient during a telehealth visit this was no more challenging than standing on a flat surface. It became evident that the pillow was fully compressed and not providing the intended dynamic base of support. A change was made to a firmer pillow and the intended balance challenge was achieved. Had it not been for telehealth, this patient would likely have been standing on a compressed pillow, day in and out, not obtaining the neuromuscular benefit of the exercise. Other exercises in the program would perhaps also be misinterpreted, and the duration of recovery potentially unnecessarily extended. Periodic telehealth visits as part of a rehabilitation program for this population provide the opportunity for in-home instruction which may be superior to traditional all in-person care.

Telehealth also augments rehabilitation of the young athlete population by providing additional scheduling options which help to ensure continuity of care. Busy family life makes attendance unpredictable and most youth are dependent upon others for transportation. It is not only the lives of the patients which affects their ability to travel to a visit, but the lives of their parents/caregivers and siblings as well. Changes in schedules of a brother or sister and unexpected work obligations of parents/caregivers can cause a cancelation. When a family may not be able to travel to an appointment, they may be able to keep their visit via conversion to telehealth, preventing an interruption in care. Telehealth also provides the opportunity for a brief visit to review and update a home program when adjustments are indicated but a full visit is unlikely to be required. A family may be hesitant to travel for a brief visit in-person, but happy to attend a brief visit via telehealth. Both advantages keep the patient and family engaged without interruptions in treatment, optimizing the episode of care, possibly maximizing the pace of recovery, and in the case of a brief visit, also provide a direct cost reduction to insurers.

**DISCUSSION**

While virtual visits cannot completely replace in-person treatment, consideration should be given to a new practice model for care of the young athlete where telehealth is provided in conjunction with in-person visits. Telehealth does not simply need to be an alternative to in-person care, and can be utilized in a "hybrid" model. The ability to observe movement patterns in the patient’s home environment and sports setting, to instruct parents/guardians in
exercise guidance while at home, to custom tailor the home program to the patient's learning abilities and access to exercise equipment/substitute household items, and to provide additional scheduling options, all contribute to a potentially enhanced treatment process. This process may mitigate some of the problems related to ineffective home program performance in the young athlete population, which can have a detrimental impact on recovery. There is a potential cost savings associated with this model if it yields a more rapid recovery and requires fewer skilled visits. This could incentivize insurers to cover telehealth services as an adjunct to in-person care. Investigation of patient outcomes, ideal number and timing of telehealth visits in an episode of care, and cost effectiveness of this blended model compared to in-person alone would be a productive next step.  

DISCLOSURES
The author reports no relevant disclosures.

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Invited Clinical Commentary

The Use of Big Data to Improve Human Health: How Experience From other Industries Will Shape the Future

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Keywords: Health, Data Science, Machine Learning, Technology, Biometrics, Human Performance, Artificial Intelligence, Medicine, Occupational Health, Sport, Military, Statistics

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'Data science' represents a set of mathematical and software development related techniques that are applied across a wide range of problems and industries. Practitioners of data science in human health-related domains typically see a world that differs substantially from practitioners in other domains such as advertising, finance, e-commerce, manufacturing, or social networking. This commentary discusses what those differences are (Project vs Product Focus, Independent vs Integrated Efforts, Causality vs Prediction Driven, Statistical vs Machine Learning Centricity) why they exist, and the future convergence that we believe is on the horizon. The concepts discussed can provide a starting point in which health and human performance-focused stakeholders can begin to align well-established data science applications from other domains to further enable innovative health and performance solutions.

INTRODUCTION

'Data science' represents a set of mathematical and software development related techniques that are applied across a wide range of problems and industries. Practitioners of data science in human health-related domains typically see a world that differs substantially from practitioners in other domains such as advertising, finance, e-commerce, manufacturing, or social networking. Here we discuss what those differences are, why they exist, and the future convergence that we believe is on the horizon.

DATA SCIENCE CULTURE IN HEALTH DOMAINS VS OTHERS

The application of data science to problems related to human health has been shaped by a long history with clinical research studies used to determine the effectiveness and safety of medical treatments and medications. The structure of these studies is guided by regulatory bodies like the US Food & Drug Administration (FDA), and disciplines like biostatistics and epidemiology evolved to guide the appropriate application of data science to medical problem domains - research studies are central to both disciplines.

This long association of health-related data science with research studies focused on medical treatments has created a data science culture with distinguishing characteristics. Though other domains like finance, e-commerce, manufacturing, advertising or social networking are not monolithic, their data science cultures show distinct contrasts with health domains. Table 1 highlights some key differences that are discussed in subsequent sections.

FOCUS: PROJECT VS PRODUCT

PROJECT FOCUS

Data science efforts in health focus on clinical research studies. Typically, a study is conducted to answer a specific set of questions in a fixed time period. The medical approach comes with constraints such as availability of data, clearly specified outcomes, available resources and a justifiable benefit for the effort.

PRODUCT FOCUS

In other domains, data science is most often applied as an ongoing component of product/service development and delivery. Data science is applied incrementally and opportunistically to meet evolving needs of products, and commitments to data science can be long term and open-ended.
CAUSALITY:

Many health-related problems are complex with multifaceted relationships between dependent and independent variables that are subject to change over time (emergent). Determination of causality is quite difficult. Sometimes, the establishment of a causal relationship is simply not feasible - even when the data supports predictive relationships. Many health-related problems are complex with multifaceted relationships between dependent and independent variables that are subject to change over time (emergent).

SIGNIFICANT EXAMPLES INCLUDE:

- Fraud detection
- Recommendation engines
- Search and SEO
- Language translation services
- Self-driving vehicles & other machine vision applications

EFFORTS: INDEPENDENT VS INTEGRATED DATA SCIENCE

INDEPENDENT DATA SCIENCE EFFORTS

In health domains, the people who conduct the analyses are typically independent of the people who use the results generated from the analyses. In some cases, this is a mandated order to ensure the objectivity of the analyses. In general, data science in health domains is conducted by dedicated specialists who provide results through studies to practitioners such as doctors and other medical professionals. Often data science is conducted by academics who are incentivized toward peer-reviewed publications rather than other forms of result dissemination or implementation. Data science work is concentrated in a relatively small group of specialists.

INTEGRATED DATA SCIENCE EFFORTS

Product-oriented domains may also have dedicated data science teams that do project-oriented work, but that work is a small fraction of the data science work that is integrated into product delivery teams. The scope of ‘data science’ in a product effort is expansive and includes roles such as instrumentation & data engineering, Machine Learning (ML) engineering, & ML operations. The ‘modelling work’ constitutes only a small portion of the data science related work in product development and delivery organization.

DRIVERS: CAUSALITY VS PREDICTION

CAUSALITY-DRiven

A primary goal in medical research is to find ways to positively change health outcomes for populations or individuals. Bio-statistical inquiry, therefore, has focused on understanding cause and effect relationships, for example:

- Is the treatment effective?
- Does a medication produce adverse side effects?
- Does an environmental condition lead to disease?

The quest for understanding causal relationships strongly shapes how data science is applied. Common practice is to use randomized controlled trials to test easily understood and actionable hypotheses relating cause to effect. Determination of causality is quite difficult. Sometimes, the establishment of a causal relationship is simply not feasible - even when the data supports predictive relationships. Many health-related problems are complex with multifaceted relationships between dependent and independent variables that are subject to change over time (emergent).

PREDICTION-DRIVEN

In other domains, applications of data science are less pre-occupied with causality - prediction is the primary focus. Consider relevant and important questions such as:

- Given a set of measured conditions, what is the probability of rain?
- Does a given transaction history imply potential fraud?
- What is the best match for a search term?
- Is the current state of the system anomalous?
- What does this photo most resemble?
- What additional product might this person add to their checkout cart?

Removal of a strict causality requirement opens the door to an expansive set of data science analysis options. Analysis can be entirely data-driven, i.e., the investigators can explore a dataset looking for patterns with no constraints on what can be a feature/factor/variable and learn to exploit those patterns as we see fit. Any method or approach that shows predictive power is a viable option for data science pursuits.

MODELING APPROACHES: STATISTICAL DATA VS MACHINE LEARNING

STATISTICAL DATA CENTRIC MODELS

Statistical data model-based approaches are entrenched in health-related data science culture. These approaches are characterized by the following:

- Preference for a set of familiar linear algorithm-based methods that support a direct approach to explanation.
- Exclusion of 'black box' prediction techniques.
- Focus on a small number of predictors that are ‘well understood.’
- Data set sizes are small to medium.

Table 1. The Two Data Science Cultures and their Key Differences

<table>
<thead>
<tr>
<th>Health Data Science Culture</th>
<th>Culture in Other Domains E.g. Finance, eCommerce, Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discrete Project Focus</td>
<td>Ongoing Product Focus</td>
</tr>
<tr>
<td>Independent Data Science Efforts</td>
<td>Integrated Data Science Efforts</td>
</tr>
<tr>
<td>Causality-driven</td>
<td>Prediction-driven</td>
</tr>
<tr>
<td>Statistical Data Model Centric Methods</td>
<td>Machine Learning (ML) Centric Methods</td>
</tr>
</tbody>
</table>
• Statistical significance criteria utilized.

MACHINE LEARNING CENTRIC MODELS

The machine learning culture present in other industries is very diverse but several aspects contrast with statistical data model cultures, which include:

• A preference for non-linear methods, particularly ANNs (Artificial Neural Networks).
• Separation of prediction and explanation into independent analyses.
• Use of many features and use of machine learning-based feature learning.
• Many applications have access to ‘big data.’

In healthcare, it is generally assumed that a data science model needs to be understandable and trustworthy by people (like doctors) who consume those models but are not able to perform the data science analysis themselves. This constraint makes the use of new mathematical techniques or more complex approaches to feature learning or engineering quite difficult. Many product-oriented domains are free from this constraint and the driving goal is simply maximum predictive power. Also, many applications in non-health domains are not governed by the oversight and regulation present in health domains whereby the ability to explain results is not explicitly required in all cases.

Some differences in culture are simply due to an earlier and less constrained move into new machine learning techniques in domains outside of healthcare. Healthcare draws more strongly from statistics, biostatistics, and epidemiology academic programs while other domains draw more from computer science and engineering; the latter were earlier to introduce machine learning into curriculums and less informed by prior statistical methodological practices. Because of the long history, healthcare data science practice has evolved more slowly and cautiously than many other domains. 20 years ago, Leo Breiman highlighted this reluctance to diversify methodologically in his famous paper about the "two cultures" of statistical modelling,1 which is still a subject of debate today.

One other driver for the use of machine learning are ‘big data’ situations where voluminous streams of data are available for model learning. Whether it be sensor or transaction data, large volumes support accurate pattern recognition, and an ongoing stream can support continuous model improvement. Much of the rapid progress in machine learning applications is directly attributable to ‘big data’, and more recently this type of data availability is becoming increasingly relevant in healthcare domains as well.

OPPORTUNITY THROUGH CONVERGENCE

Existing healthcare related data science culture exists for a reason. The unique demands in ensuring safe and effective medical treatments make clinical research studies a necessity, and warrant caution with the introduction of new techniques and technologies. However, fuelled by the exponential expansion of health-related data and of new uses of data, practices from other domains are inevitably making their way into a broader definition of health data science.

There are already many examples where the characteristics discussed previously (product centrity, integrated data science, and ML-tech centricty) are already present in health-related applications, for example:

• **Wearables and associated health applications:** Wearable devices produce big data streams that support continuous model learning and a host of application possibilities for sport performance, sleep monitoring, health assessment, e.g.
  - Oura, Apple Watch, Fitbit, Garmin, Amazon Halo
• **Automated assistance:** Leveraging advanced NLP (Natural Language Processing) capabilities, bot-based applications are emerging to provide assistance to people in many contexts including mental health.
• **Smart exercise equipment and applications:** Highly instrumented training systems that use ML/AI (Machine Learning/Artificial Intelligence) to guide the user toward better health outcomes and improved physical performance, e.g.
  - Peloton, Mirror, Blast
• **Radiology & pathology:** Radiologists and pathologists can now leverage a rich set of image recognition technologies and approaches from ML/AI that were initially developed on other problems like NN-based image recognition and shape detection in consumer and manufacturing applications.
• **Drug discovery:** While clinical trials are still required to approve drugs for use, the discovery of potential drug targets is being done using ML/AI techniques initially developed for other purposes such as search or data mining in other domains.

Applications of data science such as these represent only a first phase of evolution where health data science retains some distinct characteristics, but in aggregate looks more and more like other application domains. The healthcare community requires new big data approaches to move forward into a more efficacious and cost-effective future. With Artificial Intelligence approaches, the ‘sky appears to be the limit,’ but we must learn from the experiences and advances of other industries to make the most of these new technologies safely and with optimal health and medical outcomes.

DISCLOSURES

Two of the authors, Olsen and Atkinson, are employees of Sparta Science and Hewett is Chairman of the Scientific Advisory Board of a data science company.

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The Use of Big Data to Improve Human Health: How Experience From other Industries Will Shape the Future
REFERENCES

The International Journal of Sports Physical Therapy is pleased to publish abstracts from the 11th Orthopaedic Summit (OSET) taking place in Las Vegas, December 11-14, 2021.

The IJSPT hosted the first annual research forum and reception at OSET, sponsored by ATI Physical Therapy and Hyperice.

The abstracts presented in the following pages were selected by the OSET Research Committee and editorial staff of the IJSPT. After careful review, a total of 20 research abstracts were accepted and presented at OSET 2021. Awards for outstanding abstracts were presented on December 11th.

The 2021 abstracts include contemporary orthopaedic and rehabilitation topics across various research designs. Each abstract presents only a brief summary of a research project/presentation and does not permit full assessment of the scientific rigor with which the work was conducted. While the abstracts offer only preliminary results that may require further refinement and future validation, they do serve an important role of sharing new research ideas and rehabilitation advancements. This sharing of ideas helps to encourage dialogue among researchers, clinicians, and educators that will ultimately contribute to the orthopaedic and rehabilitation body of knowledge. We strongly encourage authors to continue pursuing publication of their research as a full manuscript.

Thank you to all submitting abstracts for consideration. We look forward to another outstanding season of submissions for OSET 2022.

Phil Page PhD, PT, ATC
Chuck Thigpen PhD, PT, ATC
OSET Research Committee Co-Chairs
THE EFFECT OF STRENGTH OR ENDURANCE TRAINING PROGRAMS ON STRENGTH AND ENDURANCE MEASURES OF THE SUPRASPINATUS AND INFRASPINATUS

Adair K,1 Bauer A,1 Kerns G,1 Roman G,1 Sones S,1 Porter D,2 Smith B,1 Manske R,1

Background: Shoulder pain is the third most common cause of musculoskeletal pain, with the most common diagnosis being rotator cuff disease. One of the factors causing this pain is the loss of strength or endurance of the rotator cuff muscles. The muscles that are most affected include the supraspinatus and infraspinatus, which allow external rotation and abduction and help to provide dynamic stability. Due to the prevalence and subsequent high cost of treating shoulder dysfunction, it is imperative to determine the most effective and efficient rehabilitation program.

Purpose: The purpose of the present study was to compare the effect of either a strength or endurance training program on the rotator cuff muscles of the shoulder.

Study Design: Randomized Controlled Trial.

Methods: The participants were comprised of 60 healthy graduate students, with a total of 52 participants who completed the study. A 12-week training program randomly placed participants into either the control, endurance, or strength training group. Participants were then randomly assigned a treatment arm where they conducted 6 exercises that targeted mainly the posterior rotator cuff muscles. Pre-testing consisted of strength assessment via a handheld dynamometer for shoulder flexion, abduction (ABD), external rotation (ER), and internal rotation (IR), while endurance was assessed using a side-lying external rotation timed endurance test. While both training groups performed the same exercises, those placed in the strength program were instructed to complete a higher intensity (using the OMNI-RES scale) and lower volume, while the endurance program was instructed to complete a lower intensity (using OMNI-RES scale) and a higher volume. Three sets of each exercise were performed, and when unable to perform them with minimal fatigue and an OMNI-RES score below the target range, they advanced to the next level of increased resistance. Compliance was tracked through weekly log sheets. Posters demonstrated the 6 exercises targeted shoulder ER and abduction.

Results: The strength training group showed an increase in ABD, ER, and IR strength. ABD showed an average increase in 2.19 pounds and ER 2.25 pounds. Since the exercises in the training program emphasized strengthening of the supraspinatus and infraspinatus, increases in ABD and ER strength were expected. IR strength showed an average increase of 3.76 pounds and while this secondary increase in IR was welcomed, it was unexpected. Increases in IR strength may have been due to an overall increase in dynamic shoulder stability gained by the exercises performed. Flexion strength did not show a significant increase. This was expected as the exercises were not specific to those muscles.

The endurance training group demonstrated a significant increase in ER endurance with an average improvement of 27.16 seconds. The endurance group showed no significant difference for all four strength measurements of the treated and untreated arm. However, while insignificant, the endurance group did yield strength gains for all four strength measurements except IR for both the treated and untreated arm.

Discussion/Conclusion: The study results were as predicted regarding both the strength and endurance training groups. Each group demonstrated increases in their perspective training modes. Based on our results from this study, these specific training protocols may be beneficial for targeting posterior shoulder muscles. The conclusion of our research raises the question of which is the best protocol regarding strength or endurance training for those with rotator cuff pathology or pain. Clinicians would benefit from future research targeting patients with rotator cuff pathology and the training program's ability to resolve and prevent injury in the long-term.

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IMPACT OF USING AN ONLINE REHABILITATION PROGRAM FOR LOW BACK PAIN COMPARED WITH TRADITIONAL PHYSICAL THERAPY: A PILOT STUDY

Bray J

Background: The recent Covid-19 pandemic has demonstrated the need for alternatives to face-to-face physical therapy services. Virtual physical therapy services and online rehabilitation programs are becoming more popular throughout the United States. Little research has been conducted to establish the effectiveness of these online programs.

Purpose: The purpose of this study is to investigate if an online interactive rehabilitation program improves patient pain and return to function for subjects experiencing low back pain. In addition, to investigate the outcomes of an online interactive rehabilitation program compared to traditional physical therapy.

Study Design: Case Report.

Methods: This is a non-randomized clinical study of subjects that engaged in the RecoveryOne web and app-based program for recovery from low back pain compared to traditional care in the literature. Each participant was asked to complete a visual analog pain scale and an Oswestry Disability Index (ODI).

Results: The 40 subjects who completed a VAS at 4 weeks demonstrated a mean decrease of 1.275 on the visual analog scale with a p of .000. The 25 subjects who completed an ODI at 4 weeks had a mean decrease of 3 with a p of .023. The 24 subjects who completed a VAS at 8 weeks demonstrated a mean decrease in VAS of 2 from the beginning of treatment with a p of .000.

Discussion/Conclusion: Online rehabilitations program may be a viable alternative to face-to-face physical therapy in reducing pain and improving function in patients with non-surgical low back pain. Patients who have been diagnosed with low back pain saw a decrease in pain and increase in function after 4 weeks and an overall decrease in pain at 8 weeks utilizing an online interactive rehabilitation program that was statistically significant. An online interactive rehabilitation program may be an alternative to traditional physical therapy.

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University of St. Augustine for Health Sciences
THE FATIGUE INDEX: AN OVERLOOKED COMPONENT OF CRITERIA FOR RETURN TO SPORT (RTS) FOLLOWING UPPER EXTREMITY INJURIES AND USING UPPER EXTREMITY FUNCTIONAL PERFORMANCE TESTS (UEFPT)

Davies GJ, Bargeron S, Connolly A, Hackmann K, Lane T, Riemann BL

Purpose/Hypothesis: There is a lack of evidence on the effects of fatigue on UEFPT which may influence RTS decisions. The purpose was to investigate effects of fatigue on UEFPT. We hypothesized the fatigue protocol would result in decreased performance.

Materials/Methods: Forty-six participants, ages 21-34 years old (22 females) (mean age 24.7, mean weight 74.9 kg, mean height 170.2 cm) completed 3 testing sessions. First session was to establish 10-repetition maximum using seated landmine press, and weight for the fatigue protocol used 70%. The operational definition of fatigue was unable to keep up with the metronome, demonstrated compensations or lacked full range of motion for 3 reps. Sessions 2 and 3 consisted of one of the UEFPT as a pre-test, followed by fatigue protocol, finishing with same UEFPT as a post-test. Randomization determined testing sequence and which arm was tested. The UEFPTs were the closed-kinetic-chain-upper-extremity-stability-test (CKCUEST) and the seated single-arm shotput test (SSASPT).

Results: Using a paired t-test, CKCUEST demonstrated a significant decrease from pre-test to post-test (p < 0.001). SSASPT demonstrated significant decreases for both dominant (Dom) and non-dominant (Non-Dom) arms from pre-test to post-test (p < 0.001, p < 0.001).

Conclusions: Results indicated fatigue significantly reduced the CKCUEST and SSASPT post-test values supporting our hypothesis. The results suggest fatigue plays a role in decreasing performance on the UEFPT and should be considered for RTS.

Clinical Relevance: If the patient performs the UEFPT in a non-fatigue state, passes, re-tests in a fatigue state and passes by not decreasing more than the MDC, we recommend discharging the patient as long as they have met all the other criteria. However, if the patient performs the UEFPT in a non-fatigue state, passes, re-tests in a fatigue state and fails it by decreasing more than the MDC, we recommend continuing rehabilitation to increase endurance and work capacity.

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THE EFFECTS OF DRY NEEDLING ON RUNNERS: A RANDOMIZED CONTROLLED TRIAL

Dewald M,1,2 Whitten B,2 Reynolds A,2 Semprini J2

Background: Runners are frequently plagued with injuries and are often prescribed hip strengthening as an intervention. While the efficacy of hip strengthening as an intervention is understood, less can be said about how ancillary interventions affect it. A common intervention amongst runners is dry needling. While dry needling has been shown to be effective in treating pain, less is understood about its impact on strength and function.

Purpose: The purpose of this study is to determine the effects of dry needling on hip strength and function in runners compared to sham dry needling when both are completed with a progressive resistance hip strengthening intervention.

Study Design: Randomized Controlled Trial.

Methods: Ten subjects between the ages of 20-25, who routinely run, were randomized into either true dry needling and exercise group (n=5) or a sham dry needling and exercise group (n=5). The subjects were blinded to their intervention and the researchers were blinded to the treatments. Subjects completed a standardized progressive resistance exercise program with instruction 3x's/wk for 8 weeks. Once a week subjects either received dry needling with monofilament needles or sham needling with the metal handle of the monofilament needles to the gluteus maximus, gluteus medius, tensor fascia latae, and the piriformis; supervision was provided for the progression of the hip strengthening program at this time as well. The primary outcomes collected were isometric hip extension, abduction and prone external rotation strength with a dynamometer and functional measurements with the Modified Star Excursion test.

Results: No significant difference was noted between the two groups at each of the three testing times (p<.05) for strength. No significant findings were noted within either group for hip extension measurements. Significant within group difference were noted for the sham group for right hip external rotation between week 4 and week 8 (p=.001) as well as between week 1 and week 8 (p=.004). Left hip external rotation also saw significant within group findings from week 4 to week 8 (p=.02) and week 1 to week 8 (p=.01). There was no significance within group differences noted for hip abduction measurements.

No significance was found between the treatment and sham group with the Modified Star Excursion test. The paired samples t test did show significant difference within DN from week 1 to 8 for left anterior, left posteromedial and left posterolateral (p=0.036, p= 0.001, p=0.049 respectively). The sham group showed significant difference at all three time periods for right posteromedial (p=0.039, p=0.009, p=0.009). Right posterolateral showed statistically significant difference at weeks 1-4 (p=0.036), while left posteromedial showed statistical significance at weeks 4-8 (p=0.026).

Generally, all groups and directions showed trending and significant improvements in strength and function, without significance for whether they received dry needling or sham dry needling.

Discussion/Conclusion: This study found that dry needling does not add to the intervention of hip strengthening in runners when assessed with isometric hip strength and the Modified Star Excursion test. However, the expectations and the needs of runner should be considered when deciding on intervention options beyond a simple biomechanical framework. The results of this study should be considered cautiously secondary to the low number of subjects. There is limited research regarding the effects of dry needling on strength and function in runners, more studies are needed to further investigate the potential benefits of dry needling in runners.

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TREATMENT OF A PROFESSIONAL POLE VAULTER WITH INSERTIONAL ACHILLES TENDINOPAHY USING TENDON FENESTRATION, SYMPTOMS AND OUTCOMES CORRELATE WITH TENDON THICKNESS AND TENDON STIFFNESS: A CASE STUDY

Dewald M

Introduction: Achilles tendinopathies are common and can occur during the peak of an athlete's career. Currently, the impact of a rehabilitation program on the biomechanical properties of Achilles tendons are poorly understood, with conflicting evidence. Tendon fenestration dry needling is in its infancy, with promise for chronic tendinopathies. The purpose of this case is to present a novel treatment of using tendon fenestration of the Achilles tendon, followed by a traditional tendon loading program, and the correlations of the biomechanical properties of the Achilles tendon for a professional pole vaulter with insertional Achilles tendinopathy.

Case Description: A 28-year-old professional pole vaulter with a 2-year history of left insertional Achilles tendinopathy, limiting her ability to compete, was treated initially with tendon fenestration followed by a traditional tendon loading program. The patient had pain with palpation at the Achilles insertion, pain with passive dorsiflexion and loaded plantarflexion. Her VISA-A at the evaluation was 57%. Ultrasound imaging of the Achilles showed thickening at 8.0 mm vs 6.0 mm of the right; however, no interruptions of the internal fibrillar structure of the tendon. Tendon stiffness was measured with the MyotonPro, a myotonometer, that has been shown to be both a reliable and valid tool for tendon biomechanical measurements. Using the mean of 3 measurements, the left tendon stiffness was 733 N/m while the right was 822 N/m, an 89 N/m difference.

Outcomes: Over the course of 4 months, the VISA-A improved 20 pts (MCID 6.5 pts), ultrasound imaging showed decreased thickness by 24% from 8.0 mm to 6.1 mm, myotonometer measurements showed increased Achilles tendon stiffness from 733 N/m to 852 N/m, a 120 N/m increase. There was a strong positive correlation between tendon stiffness and VISA-A (r = 0.75). There was stronger negative correlation of tendon stiffness and tendon thickness (r = -0.89) The patient was able to return to pain free running and jumping at this point.

Management: Tendon fenestration dry needling was completed on the first two sessions, with 10 parallel passes of dry needles towards the Achilles insertion on the calcaneal tuberosity, starting about 2 cm proximal. Isometrics and a heel lift were used the first two weeks. Following two weeks, a traditional tendon loading program was initiated. The tendon loading program was progressed once a week over the next 4 months, initially following the Silbernagel Protocol and then progressing using the Baxter et al. loading index to continue to incrementally load the Achilles tendon with lower extremity strengthening and plyometrics.

Discussion: This case demonstrates that tendon fenestration dry needling may be a promising addition to the treatment of chronic insertional tendinopathy. Biomechanical properties improved simultaneously as the tendon loading program progressed, while the symptoms and outcomes improved on the VISA-A. This case also demonstrated that tendon thickness can change incrementally with the progression of rehab, symptoms, and outcomes. Consistent, strict adherence to a tendon loading program with highly structured, incremental progression lead to the successful return to very high-level athletics for an international level athlete who was limited with her ability to compete for two years.

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SHORT-TERM EFFECTS OF DRY NEEDLING ON HAMSTRING LENGTH: A RANDOMIZED CONTROLLED TRIAL

Dewald M,1 Deiter A,2 Gross A,2 Moravec G,2 Wills D2

Background: An impairment in hamstring length is commonly encountered in the clinic and has been linked to a variety of pathologies. While there is promising research on the impact of dry needling for pain, less is understood regarding muscle length.

Purpose: The purpose of this study is to identify the short-term effect of dry needling on hamstring length in an adult population being treated with dynamic stretching.

Study Design: Double Blinded, Randomized Controlled Trial.

Methods: Twenty-three subjects volunteered with 20 subjects being included after identifying hamstring length impairments of greater than 20 degrees with the 90-90 active knee extension test. Thirty-seven hamstrings from the 20 included subjects were then randomized into a control group of dynamic stretching and sham dry needling (n=21) or an intervention group of dynamic stretching and dry needling (n=16). Two treatments sessions of true or sham dry needling were completed over the course of a week, in which subjects and researchers were blinded to which subjects received dry needling or sham dry needling. The dynamic exercises were completed daily with instructions and supervision from the researchers for both groups.

Results: There was a significant change in hamstring length from pre-treatment to post-treatment in both groups combined (6 degrees, p=.009). However, no significance in hamstring length change between the dry needling and control groups (p=.74).

Discussion/Conclusion: The addition of dry needling did not alter the short-term improvements of dynamic stretching for shortened hamstring length. Based off the outcomes of this study, dynamic stretching without the addition of dry needling is sufficient to quickly improve the hamstring length of an adult with limitations. Assessing the intervention group through the lens of a case series may paint a different picture, as it would yield a significant change in hamstring length with the intervention of dry needling and dynamic exercise. Therefore, considering the context of the patient's presentation may impact the clinical decision making necessary to include dry needling with a dynamic stretching program for adults with restricted hamstring length.

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ACHILLES TENDON STIFFNESS OF DIVISION 1 CROSS COUNTRY RUNNERS: IS SYMMETRY THE GOAL?

Dewald M

**Background:** There is conflicting data on the influence of Achilles tendon (AT) stiffness on performance and injuries in athletes. Recently the assumption of symmetry has been questioned as well. For example, the greatest sprinter in history has 14% asymmetry. Should coaches and clinicians aim for symmetry or is asymmetry the norm?

**Purpose:** The purpose of this study is to identify if there is a relationship between AT stiffness asymmetry and performance or injuries in division 1 (D1) cross country (XC) runners.

**Study Design:** Case-control Study.

**Methods:** Twenty-six (20 female) D1 XC runners volunteered from a midwestern university to participate in the study at the beginning of their XC season. The means of 3 AT biomechanical measurements were collected bilaterally with the MyotonPro, a myotonometer, at the beginning of their XC season. The MyotonPro has been shown to have good to excellent intra-rater reliability and inter-rater reliability. Validity has been established against shear wave ultrasound elastography with construct validity being demonstrated as well. Per the manufacture’s recommendations, the subjects were positioned prone with a bolster positioned anterior to their distal lower leg to allow a relaxed position for tendon measurements. The measurements were completed at the midline of the AT between the medial and lateral malleoli. Historical data on injuries and performances were collected with subjective history and surveys during data collection.

**Results:** There was no correlation in AT stiffness asymmetry and performance (r = -.01). There was no difference (p = .71) in AT stiffness asymmetry of those with a history of injury (n=14, 4.9%) in the last year to those who were injury free (n=12, 5.8%). There was a significant difference in mean AT stiffness between the high (726 N/m) and low (688 N/m) stiffness AT within runners (p < .01) with the mean AT stiffness asymmetries being 5.3%.

**Discussion/Conclusion:** Challenging the assumptions of symmetry, there was no meaningful relationships between AT stiffness asymmetry and performance or injuries. In fact, there was 5.3% asymmetry in AT stiffness between D1 XC runners included in this study. Asymmetry may have evolved, developed, or been trained to its current state with good reason. Aiming to control asymmetry of a single or a few variables without a comprehensive understanding of its impact may be a shortsighted practice.

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ACHILLES TENDON STIFFNESS OF FEMALE DIVISION 1 CROSS COUNTRY RUNNERS WHO USE ORAL CONTRACEPTIVES

Dewald M, Luken E, Peters D, Polzin J, Thum J, Gustaf S

Background: Previous tendon research does not provide data on the Achilles tendon (AT) stiffness of Division 1 (D1) female cross country (XC) runners who use oral contraceptives (OC). Limited information is known about the effect of estrogen and progesterone on tendon stiffness in D1 XC athletes, with conflicting presumptions being that there is a decrease in tendon stiffness based off less inclusive data. A decrease in AT stiffness may have an impact on injury and performance in D1 female XC runners, therefore an investigation on the impact of OC is warranted. With the findings of decreased AT stiffness in athletes who use OC, coaches and clinicians may prophylactically prescribe tendon loading programs to minimize the potentially negative effects of decreased stiffness.

Purpose: The purpose of this study is to identify if there is a difference in AT stiffness among female D1 XC athletes who use OC and do not.

Study Design: Case-control Study

Methods: Twenty current D1 female XC runners volunteered from a midwestern university to participate in the study. Six of the 20 subjects use OC and 14 do not use OC. AT biomechanical measurements were collected bilaterally with the MyotonPro, a myotonometer, at the beginning of their XC season. The MyotonPro has been shown to have good to excellent intra-rater reliability and inter-rater reliability. Validity has been established against shear wave ultrasound elastography with construct validity being demonstrated as well. Per the manufacture’s recommendations, the subjects were positioned prone with a bolster positioned anterior to their distal lower leg to allow a relaxed position for tendon measurements. The measurements were completed at the midline of the AT between the medial and lateral malleoli. The average of 6 measurements, 3 per tendon, were used to calculate the mean AT stiffness of each athlete.

Results: The mean AT stiffness of the OC users measured 664 N/m, while the nonusers measured 702 N/m. The results of an independent t-test indicate significantly lower AT stiffness of D1 female XC runners that use OC (M = 664, SD = 23.35) than those who do not (M = 702, SD = 48.5), t(18) = -2.138, p = .033.

Discussion/Conclusion: Female D1 XC runners who use OC have significantly less AT stiffness. Coaches and clinicians should consider a prophylactic AT loading program to minimize potentially adverse effects of OC use. Future research should examine how a prophylactic AT loading program impacts the AT stiffness, performance, and risk of injury.

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THE EFFECTS OF VERBAL CUES ON QUADRICEPS EMG ACTIVITY DURING A QUADRICEPS SETTING EXERCISE

Frerichs C,¹ DeHope J,² Chamberlain M,³ Bassett D,⁴ Farmer B,¹ Kyvelidou A,¹ Magrini M,⁵ Grindstaff TL¹

Purpose: A quadriceps setting (quad set) exercise is commonly utilized following knee injury, but there is great variation in clinical prescription. The purpose of this study was to determine if internal, external, or visual cues result in the greatest quadriceps electromyographic (EMG) activity during a quadriceps setting exercise.

Methods: Thirty healthy individuals (15 males, 15 females; age = 25 ± 2.5 y, mass = 79.3 ± 14.2 kg, height = 176.9 ± 9.5 cm) volunteered for this study. Peak EMG amplitude of the vastus lateralis was determined during each exercise condition. Participants performed the quadriceps setting exercise and were given one of five cues in a randomized order: internal cue “tighten your thigh muscles,” internal cue “push your knee down,” external cue “push into the bolster,” external cue “push into the strap,” or visual biofeedback (mTrigger) using the cue “raise the value on the screen as high as you can.” A repeated measures ANOVA and associated post-hoc tests, with corrected alpha levels (p < 0.005), were used to determine differences in normalized EMG activity between conditions.

Results: There was a significant difference between conditions (p < .001). Post-hoc comparisons indicated both visual biofeedback (83.2 ± 24.9%) and “press into the strap” (76.8 ± 24.4%) produced significantly greater (p < 0.001) EMG activity than the push knee down (53.2 ± 27.0%), tighten thigh (52.7 ± 27.3%), or push into the bolster (50.8 ± 26.3%) conditions. There was no significant difference (p = 0.10) between the visual biofeedback and “press into the strap” conditions as well as no significant difference (p > 0.38) between the push knee down, tighten thigh, or push into the bolster conditions.

Conclusion/Significance: Visual biofeedback and pressing into the strap produced the greatest EMG activity compared to the other internal and external cues. If the clinical aim during a quadriceps setting exercise is to obtain the greatest volitional muscle recruitment, the use of visual biofeedback or pressing into a strap is recommended.

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THE EFFECTS OF CERVICAL SPINE POSITION ON SHOULDER ROTATION STRENGTH

Giordano K,1 Oliver G2

Background: Shoulder rotation strength testing is commonly used in clinical examinations of the shoulder. Populations prone to shoulder injury, such as overhead athletes and manual trades workers, place their shoulders under tremendous amounts of stress when their cervical spine is in non-neutral positions. Given standard clinical assessments test strength with a neutral cervical spine, investigation into the effects of cervical spine rotation is warranted.

Purpose: The purpose of this study was to determine the effects of a rotated cervical spine on isokinetic shoulder internal and external rotation strength.

Study Design: This was a repeated measures, within-subject, crossover study.

Methods: Fifty-two healthy individuals (170±10 cm, 73±18 kg) participated. Concentric shoulder internal and external rotation strength were tested through a 90° arc on an isokinetic dynamometer with the shoulder elevated 90° in the frontal plane and 45° anterior to the frontal plane (scapular plane). Tests were performed with the participant's cervical spine in neutral in both planes, maximally rotated contralaterally in the frontal plane, and maximally rotated ipsilaterally with the shoulder in the scapular plane. Testing order was randomized. Data were imported into MATLAB for statistical parametric mapping analysis.

Results: Rotating the cervical spine contralaterally with the shoulder in the frontal plane resulted in a significant decrease in external (p<0.001) and internal (p=0.023) rotation strength with the forearm within 15-20° of vertical. Rotating the cervical spine ipsilaterally with the shoulder in the scapular plane resulted in a significant decrease in external rotation strength (p<0.001) throughout nearly the entirety of the motion with peaks roughly around 20° and 60° from the horizontal, and internal rotation strength (p<0.001) the last 60° towards the horizontal.

Discussion/Conclusion: About 35% of patients with common neuromusculoskeletal shoulder pathologies have cervical involvement. Because populations like overhead athletes and trades workers require use of their shoulders in altered cervical spine positions, there is reason to believe cervical spine position may be responsible for the strength differences seen in this study.

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PRETIBIAL STRENGTH AND GAIT CHARACTERISTICS IN INDIVIDUALS WITH UNILATERAL PLANTAR FASCIITIS VERSUS HEALTHY CONTROLS

Granado M,1 Lohman E,2 Gordon K,3 Dafer N,4

Background: While higher ground reaction forces (GRF) have been a suspected cause of plantar fasciitis (PF), its relationship is still unclear. Muscle fatigue is known to cause higher GRFs, but no known studies have examined the relationship between pretibial strength and PF.

Purpose: The purpose of this study is to compare pretibial strength and specific gait characteristics in those with unilateral PF with gender-matched healthy participants.

Study Design: Case-control Study.

Methods: Twenty participants with unilateral PF (mean age 47 years, 13 females) were compared between involved and uninvolved feet as well as with twenty gender-matched healthy controls (mean age 43 years, 13 females). A hand-held dynamometer was used to measure the strength of tibialis anterior (TA) and extensor hallucis longus (EHL). A pressure treadmill was utilized to quantify gait parameters such as initial toe contact and max GRF.

Results: Some evidence demonstrated EHL strength to be weakened in involved feet of the PF group when compared to healthy controls (0.07 kg (0.02) vs 0.08 kg (0.03), P = 0.11, \( \eta^2 = 0.4 \)). As well, the involved side of the PF group exhibited some evidence of early toe initial contact versus healthy controls (34.6% gait cycle (10.6) vs 38.8% gait cycle (13.3), P = 0.14, \( \eta^2 = 0.4 \)). Mean max GRF was also found to be significantly higher in the PF group versus healthy controls (involved versus controls, 780.4 N (98.6) vs 700.2 N (126.9) P = 0.02, \( \eta^2 = 0.7 \); uninvolved vs controls, 789.8 N (100.0) vs 692.7 N (126.0) P = 0.01, \( \eta^2 = 0.9 \)).

Discussion/Conclusion: While no significant differences were noted with TA strength between groups, some evidence for a weak EHL coinciding with early initial toe contact during gait may exist in those with PF. This study is relevant as it possibly identifies a muscle group needing to be strengthened when treating PF.

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TREATMENT OF UNRESOLVED SEVER’S DISEASE LEADING TO POSSIBLE ACHILLES’ TENDINOPATHY IN A 15-YEAR-OLD MALE: A CASE REPORT

Grant L, Brantley S, Swiggum M

Introduction: Calcaneal apophysitis (Sever’s Disease) is one of the most common causes of adolescent heel pain, affecting 3.7 per 1000. This condition is believed to be an overuse injury that occurs due to repetitive submaximal loading and resulting microtraumas on the growth plate caused by traction of the Achilles tendon. There is currently no gold standard for diagnosis or treatment for Sever’s Disease.

Case Description: This retrospective case study evaluated the effectiveness of physical therapy treatment on a 15-year-old male who was diagnosed with Sever’s Disease at age 11 by a physician. The goal of intervention was to reduce the patient’s pain and allow for him to return to age-appropriate recreational physical activity. The subject ceased participation in track and field when initially diagnosed due to his pain. Daily bilateral heel pain, particularly during running, jumping, and quick cutting motions were still experienced when physical therapy interventions were initiated.

Clinical Impression: The patient presented with left > right heel pain on average of 6/10 on the visual analog pain scale that was worse in the mornings once he got out of bed when he bore weight through the lower extremities. He reported pain levels increased to a 9/10 during activities including pushing off the leg while scootering or while walking or jumping. Pain symptoms were occurring daily, sometimes multiple times, and episodic pain would last from 1-5 minutes. At the time of the initial evaluation, the patient demonstrated bilateral weakness with both knee flexion and extension, as well as hypomobility at bilateral talocrural joints. Patient was also tender to palpation bilaterally at mid-portion of Achilles tendons, greater than the insertional point of Achilles on the calcaneus. Treatment interventions included lower extremity strengthening, passive and active stretching, balance and manual therapies including stretches, PNF, and soft tissue techniques. Strengthening included both closed and open chain exercises as well as concentric and eccentric exercises.

Outcomes: At conclusion of treatment, the patient’s pain levels decreased from at worst 9/10, to 3/10. Duration of symptoms decreased from 1-5 minutes to 30 seconds-3 minutes. Lower leg pain occurrence was reduced from daily to only with activity. Patient’s morning heel pain was completely alleviated. The patient also had improved pain free range of motion, improved strength in all planes of the bilateral lower extremity and improved muscle flexibility as demonstrated by muscle length measurements.

Discussion: This case study demonstrated that physical therapy intervention can reduce pain severity and frequency in patients with long standing Sever’s Disease. Our episode of treatment resulted in decreased pain and improved function during both activities of daily living and leisure activities. Sever’s Disease is one of the most common diagnoses of young athletes and a common source of pain. It is reported that 16% of emergency department visits involving active children are due to posterior heel pain. At the time of this study there are no current gold standard diagnostic outcome measures or recommendations for treatment of Sever’s disease. The absence of these tools could lead to long-term effects being experienced for these patients including not returning to sport and long-term health implications. Long-term effects could also lead to psychosocial issues for these adolescents. Sever’s disease is assumed to be a self-limiting disease that resolves with activity modification and will completely resolve by the time the child’s development slows down. This study supports the need for further research of this disease to treat patients that do not recover based on the traditional treatments and expected recovery time.

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THE ROLE OF CORE BODY TEMPERATURE ON LACTATE PRODUCTION

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Background: Blood lactate studies indicate a close association between lactate threshold and fatigue. That observation led to the common concept that fatigue was caused by a build-up of lactate when individuals exceeded their aerobic capacity. The concept of lactate production causing fatigue has been disproven. Rather than lactate causing fatigue, we propose that mechanisms of fatigue result in lactate production. One of those fatigue mechanisms is limitation of ATP production in response to hyperthermia. This adaptation might be due to the inactivation of pyruvate kinase at high temperatures. If that hypothesis is correct, lactate threshold should also be temperature sensitive.

Purpose: We evaluated effects of core body temperature on lactate threshold and production of lactate. The hypothesis was that rise in core body temperature hastens fatigue during exercise, and a manifestation of this fatigue mechanism is a rise in lactate production.

Study Design: Crossover Paired Tests.

Methods: Two studies were performed. In study one, 12 college age subjects (3 females, 9 males) performed incremental graded exercise on a treadmill (SciFit). Core body temperatures (Tes) were measured with self-inserted esophageal thermocouples (Mallinckrodt Medical). Each subject completed two tests, one starting at a Tes of 37°C and one starting at a Tes of 38°C, with the order of the two tests randomized. Starting Tes was achieved by resting in a 45°C environment until the target Tes was reached. Speed of the treadmill was 3.5 mph and 0% incline, then raised 2% every 3 minutes until volitional stop. Blood lactate (Nova Biomedical) was measured at every change in workload. Lactate threshold was determined as the workload when blood lactate reached 4.0 mmol/L. We hypothesized that the 38°C tests would reach lactate threshold sooner and at a lower workload. In cross-over study two, 14 subjects (5 females, 9 males) randomly completed three trials. In one trial, the subjects, dressed in summer workout attire, simply rested at room temperature for 60 minutes. In trial two, dressed in summer attire, they rested at 45°C for 60 minutes. In trial three, subjects dressed in Personal Protective Equipment (PPE) rested at 45°C for 60 minutes. All subjects performed a five minute treadmill walk at 60% of their calculated maximal workload at the end of the 60 minute rest period. We hypothesized that only individuals with a higher starting core temperature would show a rise in blood lactate levels post-intervention. Results: In the first study, the 38°C group reached lactate threshold with an average of 220 Watts of work, while the 37°C group reached lactate threshold with an average of 263 Watts. This 43 watts difference was significant (p < 0.001). In the second study, subjects in trials 1 and 2 showed no increase in Tes or blood lactate at the end of the rest period or treadmill challenge. In trial 3, subjects showed an increase in Tes to 38.8°C at the end of the rest, but no increase in blood lactate. However, after the treadmill challenge, the subjects in trial 3 showed a more than doubling of blood lactate (p < 0.001). The lactate response was only seen in response to a mild exercise challenge in hyperthermic subjects, but hyperthermia alone did not affect their blood lactate.

Discussion/Conclusion: A state of elevated core temperature impairs the ability of subjects to respond to exercise challenges without a significant rise in blood lactate. Effective management of core body temperature may prolong sustainable efforts in training and competition before the body reaches lactate threshold.

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An impairment in hamstring length is commonly encountered in the clinic and has been linked to a variety of pathologies. While there is promising research on the impact of dry needling for pain, less is understood regarding muscle length.

**Purpose:** The purpose of this study is to identify the short-term effect of dry needling on hamstring length in an adult population being treated with dynamic stretching.

**Study Design:** Double Blinded, Randomized Controlled Trial.

**Methods:** Twenty-three subjects volunteered with 20 subjects being included after identifying hamstring length impairments of greater than 20 degrees with the 90-90 active knee extension test. Thirty-seven hamstrings from the 20 included subjects were then randomized into a control group of dynamic stretching and sham dry needling (n = 21) or an intervention group of dynamic stretching and dry needling (n = 16). Two treatments sessions of true or sham dry needling were completed over the course of a week, in which subjects and researchers were blinded to which subjects received dry needling or sham dry needling. The dynamic exercises were completed daily with instructions and supervision from the researchers for both groups.

**Results:** There was a significant change in hamstring length from pre-treatment to post-treatment in both groups combined (6 degrees, p = .009). However, no significance in hamstring length change between the dry needling and control groups (p = .74).

**Discussion/Conclusion:** The addition of dry needling did not alter the short-term improvements of dynamic stretching for shortened hamstring length. Based on the outcomes of this study, dynamic stretching without the addition of dry needling is sufficient to quickly improve the hamstring length of an adult with limitations. Assessing the intervention group through the lens of a case series may paint a different picture, as it would yield a significant change in hamstring length with the intervention of dry needling and dynamic exercise. Therefore, considering the context of the patient's presentation may impact the clinical decision making necessary to include dry needling with a dynamic stretching program for adults with restricted hamstring length.

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DOES HIGH MEDIAL ELBOW STRESS DURING PITCHING COMPROMISE THE DYNAMIC STABILIZERS OF THE ELBOW?

Mullaney MJ, McHugh MP

Background: The flexor carpi ulnaris (FCU) and flexor digitorum superficialis (FDS) are thought to provide dynamic stability to the medial elbow, with a lesser contribution from the pronator teres (PT).

Purpose: The purpose of this study was to determine if baseball pitchers with higher valgus elbow torque (an index of medial elbow stress) experience greater postgame FCU and FDS fatigue and slower subsequent recovery.

Study Design: Descriptive Laboratory/Field Study.

Methods: A pilot study was performed to identify valid tests of FCU and FDS Function. Surface EMG signals were recorded from the FCU, FDS and PT during hand-held dynamometry testing of middle finger (MF) and ring finger (RF) flexion strength in 10 healthy men (36 ± 12 yr). EMG amplitudes, expressed as percent of maximal voluntary contraction (MVC) based on standard MVC tests for each muscle, were compared between tests and muscles with repeated measures analysis of variance (ANOVA).

Field Testing was performed in NCAA D3 baseball pitchers during the Fall season and Spring preseason. MF, RF and grip strength were tested prior to, immediately after, and one day after 14 pitching performances. Elbow valgus torque was measured from an inertial measurement unit, housed in a compression sleeve, worn on the elbow during pregame bullpen pitches (removed prior to game). Pitchers were categorized as having high or low valgus torque (> or < 50 Nm; 62 ± 7 Nm vs 32 ± 3 Nm). Effect of valgus elbow torque on fatigue and strength recovery was assessed using mixed-model ANOVA.

Results: Pilot Study: MF force was greater than RF force (77 ± 11 N vs. 58 ± 11 N, P < 0.001) and neither were different between pitchers with high (n = 8) versus low (n = 6) valgus torque (P = 0.288, P = 0.541). Pitchers threw 58 ± 12 pitches with no difference between pitchers with high versus low valgus torque (P = 0.263). Pitchers with high valgus torque (n = 8) experience marked post-game MF fatigue (88% of baseline) and incomplete recovery the following day (95%), while pitchers with low valgus torque (n = 6) exhibited no strength changes (107% of baseline post game, 106% a day later; group x time P = 0.022). Similarly, pitchers with high valgus torque experience post-game RF fatigue (94% of baseline) with minimal recovery the following day (96%), while pitchers with low valgus torque exhibited no fatigue (114% of baseline post game) and no delayed strength loss (107% a day later; group x time P = 0.048). By contrast, grip strength was decreased post game (95% of baseline) and had not recovered by the following day (95%; time effect P = 0.013) but these effects were not different between pitchers with high versus low valgus torque (P = 0.143). Valgus torque explained 40% of the variance in post-game RF fatigue (P = 0.015). A combination of valgus torque and pitch count explained 57% of the variance in post-game MF fatigue (P = 0.010). Neither valgus torque (P = 0.129) nor pitch count (P = 0.845) were related to post-game grip strength.

Conclusions: Based on EMG analyses, the MF and RF strength tests provided a functional assessment of the dynamic stabilizers of the medial elbow. Based on field testing, high valgus torque at the elbow during pitching results in greater fatigue and slower recovery of the dynamic stabilizers of the medial elbow. These are the first data to show a link between elbow stress during pitching and compromised dynamic stability in the medial elbow.

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THE ROLE OF SPINAL MANIPULATION AS A MODERATOR OF CERVICAL SPINE POSITION ON SHOULDER ROTATION STRENGTH

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Background: Emerging data shows that altering the cervical spine’s position many negatively impact shoulder rotation strength. This may be problematic in populations that require strenuous use of their shoulders. Because spinal manipulations result in acute increases in cervical spine range of motion and extremity strength, there is reason to believe spinal manipulation may mitigate the deleterious effects of a rotated cervical spine on shoulder rotation strength.

Purpose: To assess spinal manipulation as a moderator of cervical spine rotation on shoulder rotation strength.

Study Design: This was a randomized control trial.

Methods: Fifty-one participants (170±10 cm, 73±18 kg) underwent concentric shoulder internal and external rotation strength testing on an isokinetic dynamometer. The shoulder was tested through a 90º arc at 60º/s with the shoulder elevated 90º in the frontal and 45º anterior to the frontal plane (scapular plane). Tests were performed with the participant’s cervical spine in neutral, maximally rotated contralaterally in the frontal plane, and maximally rotated ipsilaterally with the shoulder in the scapular plane. Testing order was randomized. Participants received either cervicothoracic spinal manipulation or a sham manipulation then were tested with the same protocol following, and 30 minutes following treatment. Multi-level regression models were used to compare peak torque.

Results: In both the frontal and scapular plane, the level 2 explanatory model was superior to the model including a group*time*position interaction, indicating spinal manipulation did not positively affect shoulder internal or external rotation strength. Time consistently had a negative coefficient, indicating both groups decreased strength over time.

Discussion/Conclusion: Current data do not suggest a thrust manipulation mitigates the effects of an altered cervical spine position on shoulder rotation strength. However, when identical models were run splitting the groups by joint cavitation rather than manipulation, models including the group*time*cavitation interaction were superior to level 2 explanatory models, with interaction estimates being positive. This provides weak evidence that cavitations may play a role in moderating shoulder rotation strength, but further research is needed.

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Evidence-based practice (EBP) encourages clinicians to make clinical decisions based on the “best-available” evidence. Clinical inference is the process of applying knowledge (best evidence) prior to action in the context of a clinical situation such as an individual patient treatment. Clinicians sometimes have difficulty in identifying the ‘best’ evidence, particularly when faced with assessing and interpreting research statistics. Statistical inference imparts results of a study sample on a represented population, while clinical inference applies results of a study on individual patients.

Statistical inference relies on several assumptions (eg, sample size, variance, distribution, homogeneity) to infer sample results on clinical populations; unfortunately, some clinical studies used in making clinical decisions fail to meet these assumptions. To compound this problem, the commonly reported “p-value” for statistical significance is of little value in clinical decision making, although most clinicians (and researchers) are unaware of this. While the p-value provides the probability of incorrectly rejecting the null hypothesis as a dichotomous “Yes-No” statistical decision, it does not necessarily provide the evidence needed to make an informed clinical decision.

Clinicians can use estimation statistics derived from representative samples to determine the clinical significance of research outcomes, thus supporting evidence-informed decision making. Estimation statistics can help clinicians identify the magnitude and direction of an outcome (effect size), range of likely outcomes in a population (confidence interval), and the best estimate of the true value of the outcome (point estimate). Clinicians should use the minimal clinically important difference (MCID) values to determine if a study’s particular outcome measure is clinically meaningful. These statistics can then be used to make a clinical inference in the context of the research outcome and the individual patient.

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Background: Clinical practice guidelines (CPGs) are designed to provide clinicians with recommendations for evidence-based interventions. Although these resources are available, research indicates many PTs fail to choose evidence-based guidelines during treatment, likely due to lack of time, resources, and generalized results. While there are many physical therapy CPGs in publication by various organizations around the world, CPGs may be of different levels of quality or difficult for clinicians to interpret.

Purpose: The purpose of this systematic review was to evaluate the quality of musculoskeletal CPGs from the Academy of Orthopedic Physical Therapy and develop a decision matrix for choosing evidence-based physical therapy interventions.

Methods: MEDLINE, PEDro, and SPORTDiscus databases were searched, while PTNow was also cross-referenced in the search. Articles were included if they meet the following criteria: musculoskeletal clinical practice guidelines developed by the AOPT within the past 10 years. Exclusion criteria included CPGs from other authors/organizations, non-musculoskeletal guidelines, and guidelines that did not use the AGREE II quality assessment tool. Data were extracted and developed into a matrix that includes musculoskeletal conditions, recommended interventions, and level of evidence for the interventions.

Results: The most-recommended interventions were therapeutic exercise and manual therapy, respectively. While many recommendations were given, few were of high-quality evidence.

Conclusion: Having access to evidence supporting optimal treatments or identifying non-beneficial treatments is important for clinicians in making decisions to guide patient treatment.

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Background: When treating ankle fractures, the presence of talar osteochondral lesions and the extent of ligamentous injury is associated with the severity of injury. The Danis-Weber classification system has been used to predict potential ligament damage.

Purpose: The purpose of this study is to validate the ligament injury patterns that have been proposed to occur with the Danis-Weber Classification and identify the cartilage injury pattern that occurs on the talus with each fracture type.

Study Design: Retrospective Cohort Study.

Methods: A prospective, multi-center foot and ankle arthroscopy registry was queried for patients who underwent arthroscopic treatment of ankle fractures from 2017 to 2020. Pre-operative and intra-operative findings were noted, including the Danis-Weber fracture classification, presence and location of osteochondral damage, and unstable deltoid, and/or syndesmotic ligaments. Kendall’s tau-b, a nonparametric correlation coefficient for ordinal variables, was used to measure the strength and direction of association between Weber fracture type and the presence of a syndesmotic injury, deltoid ligament tear, medial malleolus fracture, or osteochondral lesion. The locations of osteochondral damage were compared as percentages.

Results: 73 subjects were prospectively collected as part of a multicenter ankle arthroscopy database. Average subject age was 43 years (SD = 17) with 59% female and 41% male. A significant association between the presence of a syndesmotic injury and fracture type was identified, with syndesmotic injuries more likely occurring with a Weber C fracture (73%, $r_T = 0.44$, $p < 0.0005$). A significant association was not identified between Weber classification and a deltoid tear (23%, $r_T = 0.74$, $p = 0.47$) or medial malleolus fracture (32%, $r_T = -0.001$, $p = 0.79$). Location of the talar osteochondral lesions were as follows: 22% medial-anterior, 22% lateral-anterior, 22% lateral-central, 17% central-anterior, 9% medial-central, 4% later-posterior, 4% central. There was no significant association identified between Weber classification and the location of the osteochondral injury ($p = 0.99$).

Discussion/Conclusion: Concurrent injuries with syndesmotic disruption, deltoid ligament tears, medial malleolus fractures, and osteochondral lesions have been proposed to be associated with Weber C ankle fractures. However, in this multicenter study, only syndesmotic injuries were associated with the Weber C classification. This study found similar rates of medial malleolus fractures and osteochondral lesions in Weber B and C type fractures.

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HAMSTRING STRAIN INJURY: CLINICAL PRACTICE GUIDELINES LINKED TO THE INTERNATIONAL CLASSIFICATION OF FUNCTIONING, DISABILITY, AND HEALTH
FROM THE ACADEMY OF ORTHOPAEDIC PHYSICAL THERAPY AND AMERICAN ACADEMY OF SPORTS PHYSICAL THERAPY OF THE AMERICAN PHYSICAL THERAPY ASSOCIATION

Martin RL, 1 Cibulka MT, 2 Bolgla LK, 3 Koc T, 4 Loudon JK, 5 Manske RC, 6 Weiss L, 7 Christoforetti JJ, 8 Heiderscheit BC 9

Background: Hamstring strain injuries (HSI) are common in activities that involve high-speed running, jumping, kicking, and/or explosive lower extremity movements with rapid changes in direction, including lifting objects from the ground. Sports such as track, soccer, Australian Rules football, American football, and rugby have the highest frequency of reported injuries. HSI may result in considerable impairment, activity limitation, and participation restriction, including time lost from competitive sports. In professional sports, a HSI may be associated with significant financial costs.

Purpose: The Academy of Orthopaedic Physical Therapy of the American Physical Therapy Association has an ongoing effort to create evidence-based clinical practice guidelines (CPGs). The aims of this review were to provide a concise summary of the contemporary evidence and to develop recommendations to promote evidence-based practice.

Study Design: A systematic review

Methods: A literature review was performed from 1967 to June 2021. Individual clinical research articles were graded to support specific for diagnosis, examination, injury prevention, interventions, re-injury risk, and return to play guidelines (RTP).

Results:

Diagnosis
Clinicians may diagnose a HSI when an individual presents with a sudden onset of posterior thigh pain during activity, that is reproduced pain when the hamstring is activated and/or stretched, associated muscle tenderness with palpation and loss of function. (Weak evidence)

Examination
Clinicians should quantify knee flexor strength following HSI by using either a HHD or isokinetic dynamometer. (Strong Evidence)

Clinicians should assess hamstring length measuring knee extension deficit with the hip flexed to 90° using an inclinometer. (Strong Evidence)

Clinicians may measure the length of muscle tenderness and location from the ischial tuberosity to assist in predicting timing of RTP. (Weak Evidence)

Clinicians may assess for increased anterior pelvic tilt and abnormal trunk and pelvic control during functional movements. (Expert Opinion)

Clinicians may include objective measures of an individual’s ability to walk, run, and sprint when documenting changes in activity and participation over the course of treatment. (Weak Evidence)

Clinicians should use the Functional Assessment Scale for Acute Hamstring Injuries (FASH) to document changes from before and after interventions. (Moderate Evidence)

Injury Prevention Program
Clinicians should include the Nordic hamstring exercise with other components of warm-up, stretching, stability training, strengthening, and functional movements (sport-specific, agility and high-speed running). (Strong Evidence)

Intervention
Clinicians should use hamstring muscle eccentric training, added to stretching, strengthening, stabilization, and progressive running programs, to improve RTP time after a HSI. (Moderate Evidence)

Clinicians should incorporate progressive agility and trunk stabilization, added to a comprehensive impairment-based treatment program with stretching, strengthening, and functional exercises, to reduce re-injury after a HSI. (Moderate Evidence)

Clinicians may use soft-tissue mobilization, nerve glides, and therapeutic modalities to assist in the healing process and shorten the period of disability after a HSI. (Expert Opinion)

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Clinicians should consider the absence of an appropriately progressed, comprehensive impairment-based functional exercise program a risk factor for re-injury and programs that do not specifically include eccentric training a risk factor for re-injury as well as delayed RTP. *(Moderate Evidence)*

Clinicians should use hamstring strength, pain level at the time of injury, number of days from injury to pain-free walking, and area of tenderness measured at initial evaluation to estimate time to RTP. *(Moderate Evidence)*

**Discussion/Conclusion:** This CPG supports evidence-based physical therapy practice in the diagnosis, examination, injury prevention, intervention after injury, and risk assessment for re-injury and return to play decisions for those with a HSI.

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THE CONCURRENT VALIDITY OF STRENGTH MEASUREMENTS FOR NECK FLEXION AND EXTENSION OBTAINED BY HAND-HELD DYNAMOMETRY. A COMPARISON WITH THE MULTI-CERVICAL UNIT.

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Background: While rehabilitation and prevention of sports-related concussions have become a field of interest in physiotherapy research, so far, the relevance of neck strength in association with concussion remains unclear. Valid devices and user-friendly measuring protocols for clinical practice are needed to further investigate the importance of neck strength in rehabilitation.

Purpose: The purpose of the present study was to evaluate the concurrent validity of a user-friendly and time-efficient protocol to measure cervical flexion and extension strength using a hand-held dynamometer (HHD) and the Multi-Cervical Unit (MCU) as a reference device.

Study Design: Descriptive Laboratory Study.

Methods: The MCU and an HHD measured neck flexion and extension strength of 30 active, healthy males (mean age 27.1 years) on one measuring day. Data analysis used maximum voluntary strength values in Newton (N). Concurrent validity was determined using paired t-test and Pearson correlation. Bland-Altman plots and boxplots were used to illustrate differences between the devices.

Results: Neck flexion and extension strength were significantly different between the devices (p < 0.01). Weaker correlations between the two devices were found for flexion (r = 0.35, 95% CI: -0.02 to 0.63, p < 0.06) than for extension (r = 0.63, 95% CI: 0.35 to 0.81, p < 0.001). Bland-Altman Plots revealed sizable limits of agreement for both directions.

Conclusion: Neck strength measured with an HHD and the protocol used were different from those obtained with the MCU. The strength of the tester and deviations in positioning potentially limited absolute agreement between the MCU and the HHD. Therefore, values retrieved through different devices should be interpreted with caution and not used interchangeably by clinicians. Future studies should focus on establishing a gold standard for neck strength measurements.

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